led I, of the next PLD, as shown in that figure. The input of the last PLD 130k is tied to ground. The serial connections 180 allow the data in the PLSSR to be shifted through all 320 stages with only one data line connecting the PLDs.

Referring now to Figures 5A-5F collectively, at the beginning of a scan for a touch, the counters 158, 174 are reset to 00H, the STOP signal generated by R-S latch 172 is a logical ZERO, and the SAMPLE signal generated by the clock circuit 150 and the DISABLE signal generated by R-S latch 164 are a logical ONE. Every 20.5 μs, the logical ONE in the ring counter 156 is passed from the current stage Y_n to the next stage Y_{n+1} responsive to the YCLK. As explained above, each y-driver is held at a logical ONE (+5 VDC) for 20.5 μs. The 20.5 μs value is somewhat arbitrary, but is believed to provide a comfortable medium between very rapid scanning, which is governed by the time-constant of each conductor and which would increase the electromagnetic interference with surrounding electronic devices, and very slow scanning, which would cause the scanning rate to be too slow for digitizing the fluid stylus strokes of, for example, handwriting.

As each y-conductor is driven by its associated y-driver, the y-counter 158 counts responsive to the YCLK. Thus, the value of the y-counter 158 corresponds to the y-conductor currently being driven. The y-counter 158 is configured to be reset to 00H responsive to YCLEAR. YCLEAR is asserted responsive to a completed scan of all y-conductors.

At 19.875 μs into the 20.5 μs assertion period of each y-driver, the SAMPLE signal is asserted by placing it at a logical ZERO and placing it at a logical ONE 500 ns later, as shown in Figure 5E. Responsive to the SAMPLE signal being asserted, the PLSSR 170 latches the contents of all the x-conductors 12. Normally, all the latched x-conductor values will be at logical ZERO. If the y-conductor that is being driven to a logical ONE is touching one of the x-conductors in the manner shown in Figure 1E, then one of the latched x-conductor values will also be a logical ONE. On the other hand, if the y-conductor that is at a logical ONE is not touching one of the x-conductors in the manner shown in Figure 1E, then all of the latched values will be a logical ZERO. Immediately after latching the x-conductor values, the PLSSR 170 begins sequentially shifting all the x-conductor values responsive to the XCLK and sequentially inputting them to the R-S latch 172.

As each x-conductor value is shifted past the R-S latch 172, the x-counter 174 counts responsive to the XCLK. Thus, the value of the x-counter 174 corresponds to the x-conductor the value of which is being shifted past the R-S latch. The x-counter 174 is configured to be reset responsive to XCLEAR. XCLEAR resets the x-counter to 00H after all the x-conductor values have been shifted past the R-S latch 172, unless a ONE is detected, in which case the x-counter is cleared after the x-counter value has been latched into the x-latch 176 and before Y0 is driven.

In short, each y-conductor 18 is sequentially raised to a voltage corresponding to a logical ONE. While each y-conductor is a logical ONE, the value of all the x-conductors 12 are simultaneously latched and then very rapidly serially shifted to detect the presence of a logical ONE, which indicates a closure event as shown in Figure 1E. After each cycle of sequentially driving all the y-conductors 18, the R-S latch 164 clears the DISABLE signal responsive to Y239, thereby signaling to the microcontroller 132 that data is about to change and therefore disabling data reads by the microcontroller 132.

If none of the x-conductor values are a ONE, then no closure event has taken place and the y-counter 158 and x-counter 174 count while the y-conductors continue to be sequentially driven and the x-conductor values continue to be simultaneously latched and serially shifted.

On the other hand, if one of the x-conductor values shifted past the R-S latch 172 is a logical ONE, the output of the R-S latch 172 becomes a logical ONE thereby asserting the STOP signal. Responsive to the STOP signal being asserted the y-counter 158 and the x-counter 174 stop counting, even though the PLSSR 170 continues to shift the x-conductor values past the R-S latch 172 and the ring counter 156 continues to pass the logical ONE from one stage to the next. Thus, the moment the STOP signal is asserted, the coordinates of the touched location are contained in the counters 158, 174. The STOP signal remains asserted until the FSYNC3 signal of the next cycle becomes active.

Next, responsive to the STOP and FSYNC1 signals being asserted, the values in the counters 158, 174 are latched into their respective latches 160, 176. Finally, responsive to FSYNC2, the R-S latch 164 sets the DISABLE signal, thereby signaling to the microcontroller 132 that data is latched and available, thereby enabling data reads by the microcontroller 132.

The microcontroller 132 periodically polls the values latched in the latches 160, 176 responsive to the DISABLE signal. The microcontroller 132 then encodes the data into a format suitable for serial transmission over the serial line to the personal computer. The exact data encoding algorithm is not critical and depends entirely upon the software driver executing on the computer system; different software drivers might require the data to be different formats, as known to those skilled in the art. The data must match the software on the

computer system. Alternatively, the data can be compressed using any of the well known compression algorithms. The encoded values are transmitted out the TxD output of the microcontroller 132 via the RS-232 driver 120 to pin 2 of the DB-9 connector 140.

Alterations and modifications to the circuitry will be apparent to those skilled in the art. For example, the Y lines can be defaulted to a logical ONE and a logical ZERO passed around the ring counter 156. As another example, the drivers and receivers need not be implemented in PLDs. Rather, an application-specific integrated circuit (ASIC) could be designed and fabricated to perform the required interface functions. In addition, the 244-bit ring counter 156, the 320-bit PLSSR 170, and the other circuitry can be implemented on a single massive ASIC. Such an ASIC might use active pullups and pulldowns instead of the passive pulldown resistors 138. Such circuits are known in the art and use, for example, two NPN transistors, with the collector of the first connected to the emitter of the second, the emitter of the first connected through a resistor to a voltage associated with a logical ONE, the collector of the second connected through a resistor to a voltage near ground, the bases of the transistors connected to respective driver circuitry, and the tied emitter-collector connected to the x-conductors.

Referring now to Figure 6 a block diagram of the electronics used to interface to the dual sensor of the present invention is shown. The circuitry includes coarse y-drivers 190, coarse x-receivers 192, fine y-drivers 194, and fine x-receivers 196 all in circuit communication with coordinate determining circuitry 198. As with the circuit of Figures 5A, 5B, and 5F, each of the coarse y-drivers 190 drives a single coarse y-conductor 32. Likewise, each of the coarse x-receivers 192 receives data from a single coarse x-conductor 38.

However, the fine conductors 42, 48 are different. Each of the fine y-drivers 194 drives more than one fine y-conductor 42. Likewise, each of the fine x-receivers 196 receives data from more than one fine x-conductor 48. In Figure 6, the ratio is four fine conductors per coarse conductor along both axes. Preferably a ratio of 16 fine conductors per coarse conductor along both axes would be used. Thus, there would be fifteen coarse y-conductors 32 corresponding to the 240 fine y-conductors 42, and twenty coarse x-conductors 38 corresponding to the 320 fine x-conductors 48.

The coordinate determining circuitry 198 can be designed very similarly to the circuits of Figures 5B-5F. A pair of ring counters can be used to sequentially drive the coarse and fine y-conductors 32, 42. A pair of parallel load/serial shift registers can be used to simultaneously sample the coarse and fine x-conductors 38, 48. The circuitry 198 differs from that in Figures 5B-5F in that the intersection of the coarse conductors 32, 38 and the intersection of the fine conductors 42, 48 are used to determine the exact location of the touched region.

For example, using the device of Figure 6, the coarse intersection might indicate that the touch is four coarse rows down and five coarse columns over and the fine intersection might indicate that the touched location is three fine rows down and two fine columns over. The exact location would be determined by the fine value plus the coarse value times the number of fine conductors per coarse conductor. In the above example the exact location would be 19 (3+4x4) fine y-conductors down by 22 (2+5x4) fine x-conductors over.

Many configurations are possible for the coordinate determining circuitry 198. The critical aspect is to use both intersections of the dual sensor to determine the coordinates of the touched location. For example, the y-counter and x-counter could be implemented with two counting inputs: a count-by-four input and a count-by-one input. Like the circuit in Figures 5A-5F, the two counters would count until an intersection is detected. Unlike the circuit in Figures 5A-5F, the counters would first count by fours (i.e., count by the number of fine conductors per coarse conductors on that axis) until a coarse intersection is detected and then count by ones until a fine intersection is detected. Many circuits are possible and within the skill of those skilled in the art.

Using the dual sensor greatly simplifies and reduces the size of the electronics needed to determine the coordinates of the touched location. The 320-by-240 circuit of Figure 5B requires 560 drivers and receivers: 240 y-drivers and 320 x-receivers. By comparison, a dual sensor of the same 320-by-240 resolution could be made with 16 fine y-conductors per coarse y-conductor and 16 fine x-conductors per coarse x-conductor. A coordinate determining circuit 198 to interface to such a 320-by-240 dual sensor would need only 67 drivers and receivers: 15 individual coarse y-drivers, 20 individual coarse x-receivers, 16 individual fine y-drivers, and 16 individual x-receivers. Moreover, either the coarse and fine y-drivers or the coarse and fine x-receivers can be shared, thereby further reducing the driver and receiver count to 51. That is, the y-drivers can each drive one coarse y-conductor and sixteen fine y-conductors. In the alternative, the x-receivers can each receive data from one coarse x-conductor and sixteen fine x-conductors. Thus, the dual sensor greatly reduces the number of drivers and receivers needed to interface to the circuit.

Reducing the number of drivers and receivers reduces both the size and the cost of the electronics. The circuits require one device pin per driver and one device pin per receiver. The circuit of Figure 5B has 560 drivers and receivers requiring 560 device pins and therefore used nine large EPLDs, which could only be replaced by an equally large ASIC or ASICs. The device described in the above paragraph can be made with 67 or as little as 51 drivers and receivers, thereby allowing the entire circuit to be designed into a single EPLD or a very small ASIC. The reduction in pin-count is virtually an order of magnitude less. Consequently, a much smaller and less costly electronic interface circuit can be used with the dual sensor.

Referring now to Figures 7A-7C, another embodiment of the sensor is shown. In the previously described embodiments, the conductors were shown as being rail-like. That is, the conductors were shown as being shaped substantially like rectangular parallelopipeds with one axis substantially greater in length than either of the other two axes. However, other conductor shapes are possible.

In the previous embodiments, the possible intersection area is relatively small in comparison to the total area of the touchpad sensor surface. A significant number of blind spots exist. For example, it is conceivable that a user might draw a substantially horizontal or vertical line with the stylus that lies substantially on top of an insulator. Very few intersections would occur and therefore, the input to the personal computer would be a poor approximation of the actual touched locations. Analytically, if the conductors are the same width as the insulators, then only approximately 25% of the surface can act as a contact area. Practically speaking, this is not a serious drawback because the tip of the stylus tends to slip off of the conductor and into one of the contact areas.

Even so, other configurations can greatly increase the total contact area. Figure 7A shows one pattern of conductors 200 that results in significantly fewer blind spots. The pattern consists of circular conductive pads 202 connected by conductive isthmuses 204. The plurality of conductive paths formed by the pads 202 and the isthmuses 204 are non-intersecting and lie longitudinally, as in the other embodiments. The pads 202 and isthmuses 204 can be of the same materials as described in the previous embodiments. In Figure 7A the pads 202 are circular in shape; however, other pad shapes are possible. Preferably, the pads are such that the total contact area as a percentage of total sensor surface area is higher than that of the embodiment of Figure 1A-1C. As with the previous embodiments, the size and spacing of the pads and isthmuses depends on the desired resolution of the sensor. Preferably, the pads 202 are substantially the same size and are spaced substantially equidistant from each other. Preferably the isthmuses are substantially the same size and are spaced substantially equidistant from each other.

Figure 7B shows a touchpad sensor 210 comprising two of the patterns of Figure 7A. The first pattern has pads 202 and isthmuses 204 and the second pattern has pads 212 and isthmuses 214. The second pattern is rotated 90° such that the conductive paths of each are skewed and preferably orthogonally to each other. The two patterns are separated by insulating pads 216 at the intersections of the isthmuses 204, 214 as viewed from the top.

The relationship between the two patterns is better understood with reference to Figure 7C. Figure 7C shows the insulating pads 216, conductive pads 202, 212, and the isthmuses 204, 214. The insulating pads 216 are configured such that conductive pads 202, 212 are separated by a gap 218. As with the previous embodiments, the gap can be air or an inert gas. Also, as with the embodiment of Figure 1A-1C, the pads 212 and isthmuses 214 are disposed on a rigid substrate 220 and the pads 202 and isthmuses 204 are disposed on a flexible substrate 222. The conductive pads 202, 212 and conductive isthmuses 204, 214 can be made of the same materials and applied in the manner as the conductors described above. The insulating pads 216 can be made of the same materials and applied in the manner as the insulators described above.

Analytically, the contact area of the embodiment of Figure 7B is approximately 40% of the total area of the sensor surface. If the circular conductive pads are increased in size until they are just separated, the contact area can be approximately 75% of the total sensor surface area.

The electronics for driving the embodiment of Figure 7B is very similar if not identical to that shown in Figures 5A-5F. One possible modification is to slightly skew the resulting coordinates because in the sensor of Figures 1A-1C the adjacent contact areas are horizontal and vertical and in the embodiment of Figure 7B, the adjacent contact areas lie along diagonals.

Referring now to Figure 8, the electrical connections of the various conductors to the circuit components is shown, somewhat diagrammatically. As can be seen in Figure 8, the many integrated circuits of Figures 5A-5E are mounted on two double-sided printed circuit boards 10, 300. The printed circuit board 10 is the same board 10 used as the substrate for the embodiment of the sensor shown in Figures 1A-1E. The conductors 12 on the one side 304 of the substrate 10 are connected through vias 302 formed through the substrate 10 to the circuitry 130f-130k via circuit traces 308 on

the opposite side 306 of the substrate 10.

The other circuitry 130a-130e is disposed on the second PCB 300 and electrically connected to printed circuit traces 309. The conductors 18 on the membrane 16 are connected to electrical circuitry 130a-130e via a 240-line flexible connector cable 310 having circuit traces 312 thereon. The cable 310 can be made of the same material as the other flexible membranes 16, 36, and 46. The circuit traces 312 can be made of conductive ink like the conductors 18, 38, 42, and 48 and applied as such. The connection of the cable 310 to the conductors 18 and traces 309 is preferably by conducting adhesive 314. The adhesive can be an anisotropic conductive adhesive such as an epoxy with conducting particles suspended therein, as is known in the art. The conductors are aligned, the adhesive is applied, and the bond area is heated, and held under pressure until the epoxy sets. The anisotropic adhesive provides electrically conducting adhesion between the conductors 312 and 18 and conductors 312 and 309 and non-electrically conducting adhesion elsewhere. The substrate 300 also is preferably formed of glass-filled epoxy, such as FR4 and has mounted on the top surface additional circuit chips to perform the functions of Figure 5A-5F. Various other components (not shown) are mounted on the boards 10 and 300, such as the diodes 136 and resistors 138, both in surface mount form. The boards 10 and 300 are interconnected by stand-offs (not shown), which are well known in the art. The same arrangement of circuitry is used for the dual sensor of the present invention.

Although not necessary, the two substrates 10, 16 can be sealed with a sealing material 316. Many materials are suitable, such as transfer adhesives and their equivalents and injected adhesives. Such adhesives are known in the art and available from numerous sources, such as the 3M Company.

The following signals are communicated between the two boards 10, 300 with well known inter-PCB connectors: the 16 MHz clock, SAMPLE, FSYNC1, FSYNC2, FSYNC3, STOP, LX0-LX8, and the power supply sources. The entire structure is then enclosed in a sealable case (not shown), which can be hermetically sealed, as known by those skilled in the art. This case may include an additional flexible membrane covering the substrate 16 to improve its scratch and wear resistance.

The same type of physical sealing and mounting is applicable to a touchpad made with the dual sensor of the present invention.

While the present invention has been illustrated by the description of embodiments thereof, and while the embodiments have been described in considerable detail, it is not the intention of the applicant to restrict or in any way limit the scope of the appended claims to such detail. Additional advantages and modifications will readily appear to those skilled in the art. For example, different shapes of conductors might increase the contact area even further and still provide sufficient electrical isolation between the circuits. As another example, two fine sensors of Figures 1A-1E can be sandwiched in the manner of Figures 2A-2E and aligned such that the conductors of one overlap the insulators of another, thereby achieving a composite contact area of virtually 100%. Therefore, the invention in its broader aspects is not limited to the specific details, representative apparatus and method, and illustrative examples shown and described. Accordingly, departures may be made from such details without departing from the scope of the applicant's general inventive concept.

Claims

1. A dual sensor comprising:
   a first touchpad sensor having a first resolution; and
   a second touchpad sensor substantially the same size as said first touchpad sensor, having a second resolution, and positioned proximate to said first touchpad sensor;
   wherein said first touchpad resolution is different from said second touchpad resolution; and
   wherein said first and second touchpad sensors are configured and positioned such that a single touch of a finger, stylus, or the like is detectable by both said first touchpad sensor and said second touchpad sensor.

2. A dual sensor as claimed in claim 1 wherein said first touchpad sensor is aligned substantially orthogonally with respect to said second touchpad sensor in plan view.

3. A dual sensor as claimed in claim 1 wherein said first touchpad sensor has one fourth the resolution of said second touchpad sensor.

4. A dual sensor as claimed in claim 1:
   wherein said first touchpad sensor has first and second pluralities of conductors associated therewith;
   wherein said second touchpad sensor has third and fourth pluralities of conductors associated therewith; and
   wherein said first and second touchpad sensors are configured and positioned such that a single touch of a finger, stylus, or the like causes at least one of said first plurality of conductors to coact with at least one of said second plurality of conductors such that the

location of the touch can be determined therefrom and further causes at least one of said third plurality of conductors to coact with at least one of said fourth plurality of conductors such that the location of the touch can be determined therefrom.

5. A dual sensor comprising:

a first plurality of parallel conductors each spaced from adjacent conductors of said first plurality of parallel conductors by a pair of insulators of a first plurality of insulators;

a second plurality of parallel conductors proximate to said first plurality of conductors, positioned skewed with respect to said first plurality of conductors in plan view, and each spaced from adjacent conductors of said second plurality of parallel conductors by a pair of insulators of a second plurality of insulators;

a third plurality of parallel conductors proximate to said first plurality of conductors and each of said third plurality of conductors spaced from adjacent conductors of said third plurality of parallel conductors by a pair of insulators of a third plurality of insulators; and

a fourth plurality of parallel conductors proximate to said third plurality of conductors, positioned skewed with respect to said third plurality of conductors in plan view, and each spaced from adjacent conductors of said fourth plurality of parallel conductors by a pair of insulators of a fourth plurality of insulators;

wherein said first plurality of conductors are configured to lie substantially in a first plane;

wherein each of said first plurality of insulators extends beyond said first plane toward said second plurality of conductors;

wherein said third plurality of conductors are configured to lie substantially in a second plane; and

wherein each of said third plurality of insulators extends beyond said second plane toward said fourth plurality of conductors.

6. A dual sensor as claimed in claim 5 wherein said first plurality of conductors is aligned substantially orthogonally with respect to said second plurality of conductors and said third plurality of conductors is aligned substantially orthogonally with respect to said fourth plurality of conductors in plan view.

7. A dual sensor comprising:

a first plurality of conductors that are flexible, spaced from adjacent conductors by a first plurality of insulators, and substantially parallel to each other;

a second plurality of conductors proximate to said first plurality of conductors, substantially parallel to each other, skewed with respect to said first plurality of conductors in plan view, and spaced from adjacent conductors of said second plurality of conductors by a second plurality of insulators;

a stylus surface proximate to said first plurality of conductors for accepting pressure from a finger, a stylus, or the like;

a third plurality of conductors that are flexible, positioned proximate to said first plurality of conductors, spaced from adjacent conductors by a third plurality of insulators, and substantially parallel to each other; and

a fourth plurality of conductors proximate to said third plurality of conductors, substantially parallel to each other, skewed with respect to said third plurality of conductors in plan view, and spaced from adjacent conductors of said fourth plurality of conductors by a fourth plurality of insulators;

wherein each of said conductors of said first and second pluralities of conductors and each of said insulators of said first and second pluralities of insulators is configured and positioned such that each of said first plurality of conductors has two states: a relaxed state and a flexed state; said relaxed state being characterized by said conductor not being in electrically conducting contact with any of said conductors of said second plurality of conductors; and said flexed state being characterized by said conductor being in electrically conducting contact with at least one conductor of said second plurality of conductors;

wherein each of said conductors of said first and second pluralities of conductors and each of said insulators of said first and second pluralities of insulators is further configured such that the asserting a predetermined amount of pressure from a finger, stylus, or the like to said stylus surface causes at least one of said first plurality of conductors in said relaxed state to enter said flexed state and removing the predetermined amount of pressure from said stylus surface causes said at least one of said conductors in said flexed state to enter said relaxed state;

wherein each of said conductors of said third and fourth pluralities of conductors and each of said insulators of said third and fourth pluralities of insulators is configured and positioned such that each of said third plurality of conductors has two states: a relaxed state and a flexed state; said relaxed state being characterized by said conductor not being in electrically conducting contact with any of said

conductors of said fourth plurality of conductors; and said flexed state being characterized by said conductor being in electrically conducting contact with at least one conductor of said fourth plurality of conductors; and

each of said conductors of said third and fourth pluralities of conductors and each of said insulators of said third and fourth pluralities of insulators is further configured such that the asserting a predetermined amount of pressure from a finger, stylus, or the like to said stylus surface causes at least one of said third plurality of conductors in said relaxed state to enter said flexed state and removing the predetermined amount of pressure from said stylus surface causes said at least one of said conductors in said flexed state to enter said relaxed state.

8. A dual sensor as claimed in any of claims 4, 5, or 7 further comprising a plurality of drivers in circuit communication with said third plurality of conductors for placing an electrical signal onto any conductor of said third plurality of conductors, each of said drivers being in circuit communication with at least two conductors of said third plurality of conductors.

9. A dual sensor as claimed in any of claims 4, 5, or 7 further comprising a plurality of receivers in circuit communication with said fourth plurality of conductors for detecting an electrical signal on any conductor of said fourth plurality of conductors, each of said receivers being in circuit communication with at least two conductors of said fourth plurality of conductors.

10. A dual sensor as claimed in any of claims 5 or 7 wherein said insulators of said first and second pluralities of insulators comprise air and said insulators of said third and fourth pluralities of insulators comprise a different dielectric.

11. A dual sensor as claimed in any of claims 5 or 7 wherein said conductors of said first plurality of conductors comprise copper covered with gold flash and said conductors of said second, third, and fourth pluralities of conductors comprise silver ink.

12. A dual sensor as claimed in any of claims 5 or 7 wherein said conductors and insulators are deposited onto at least three substrates.

13. A method of fabricating a touchpad sensor comprising the steps of:

(a) affixing a first plurality of conductors onto a first substrate;
(b) affixing a second plurality of conductors onto the first side of a second substrate;
(c) affixing a first plurality of insulators onto the first side of said second substrate;
(d) affixing a third plurality of conductors onto the second side of said second substrate;
(e) affixing a second plurality of insulators onto the second side of said second substrate;
(f) affixing a fourth plurality of conductors onto a third substrate; and
(g) positioning said first, second, and third substrates such that said insulators of said first plurality of insulators are in physical contact with said first plurality of conductors, said insulators of said second plurality of insulators are in physical contact with said fourth plurality of conductors, said insulators of said first plurality of insulators prevent physical contact between said conductors of said first and second pluralities of conductors until a localized pressure is applied, said insulators of said second plurality of insulators prevent physical contact between said conductors of said third and fourth pluralities of conductors until a localized pressure is applied, said first and second pluralities of conductors are skewed in plan view, said third and fourth pluralities of conductors are skewed in plan view.

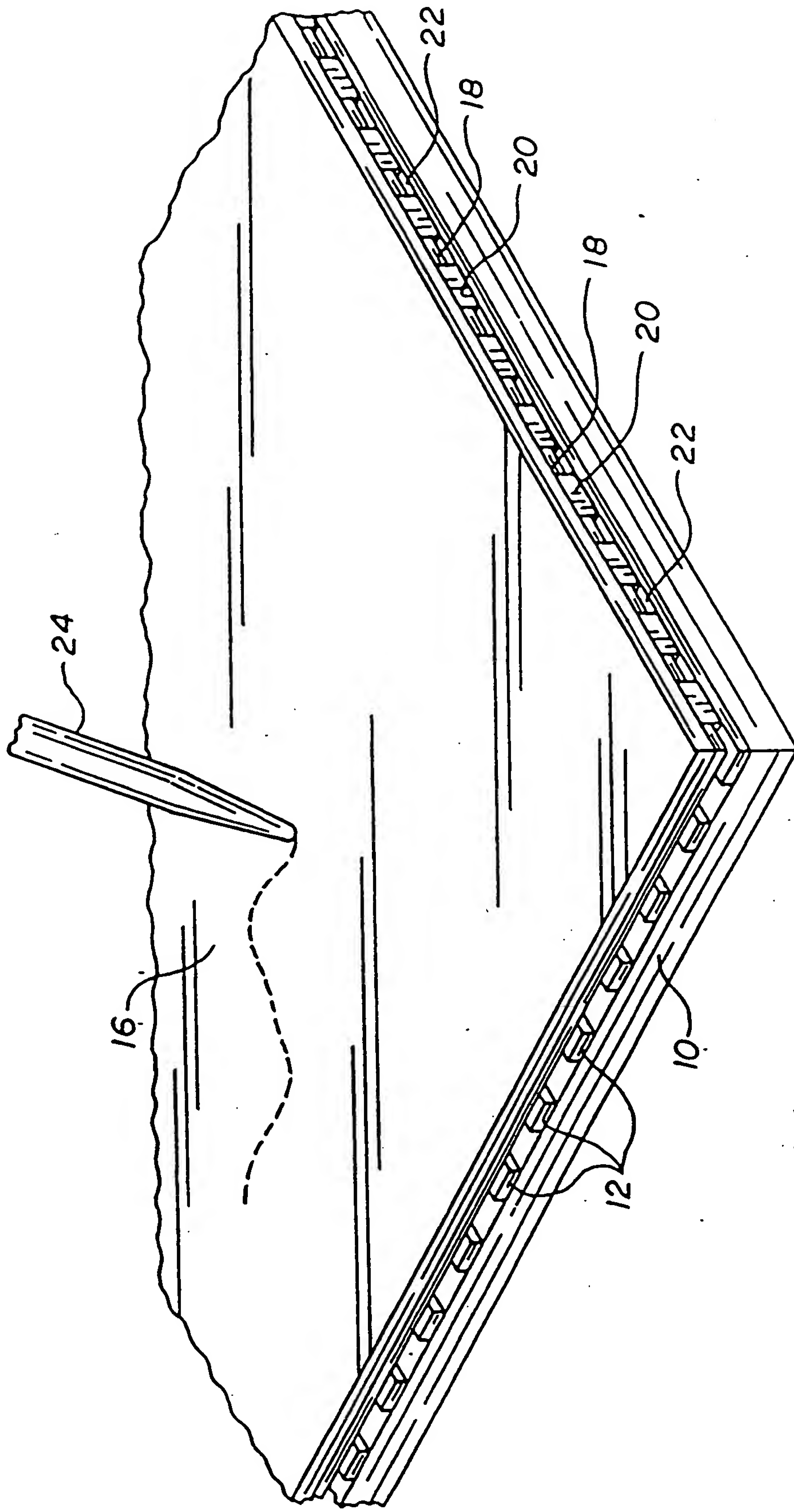


FIG. 1A

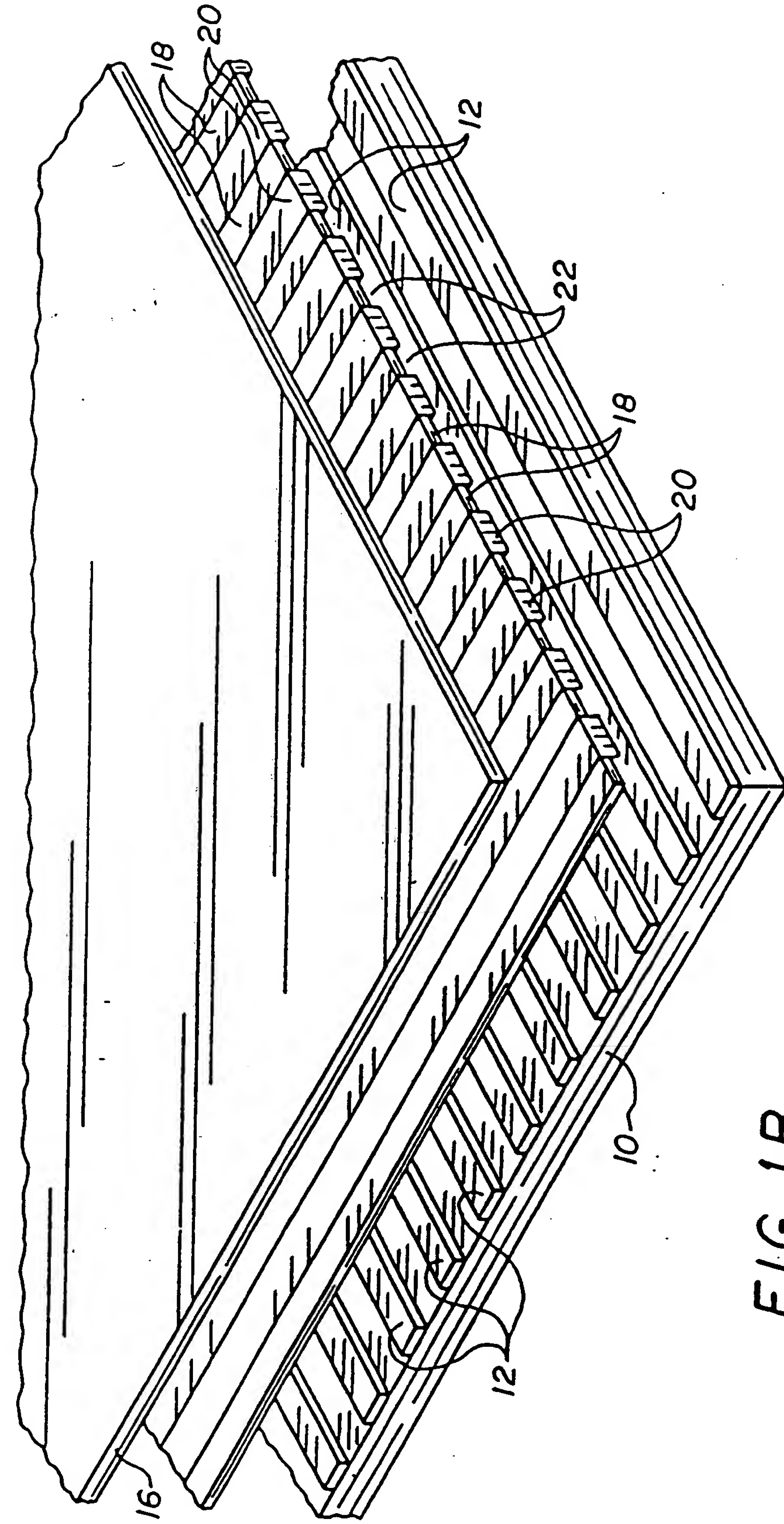


FIG. 1B

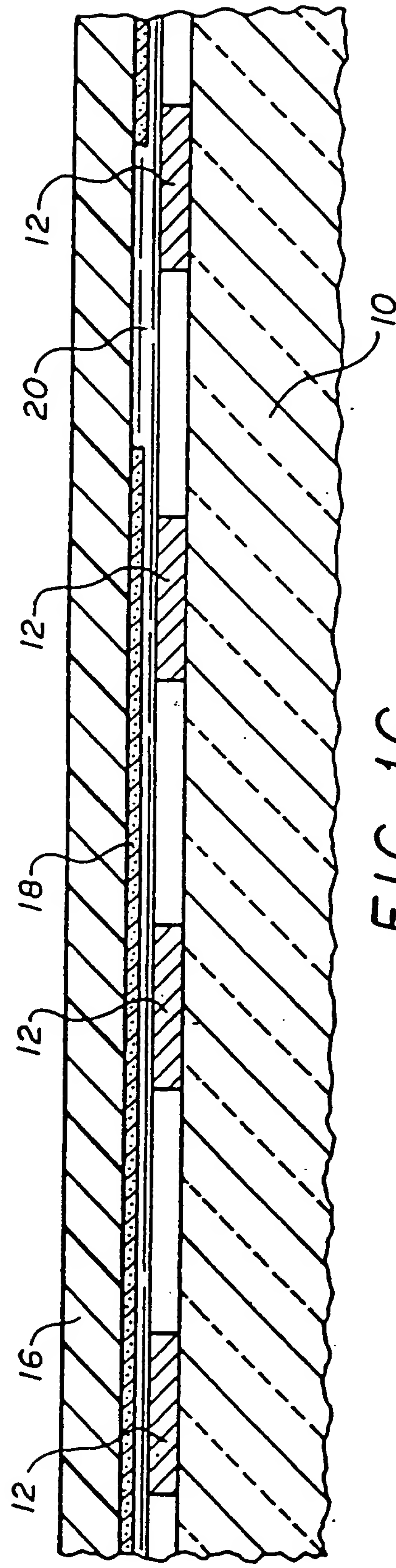


FIG. 1C

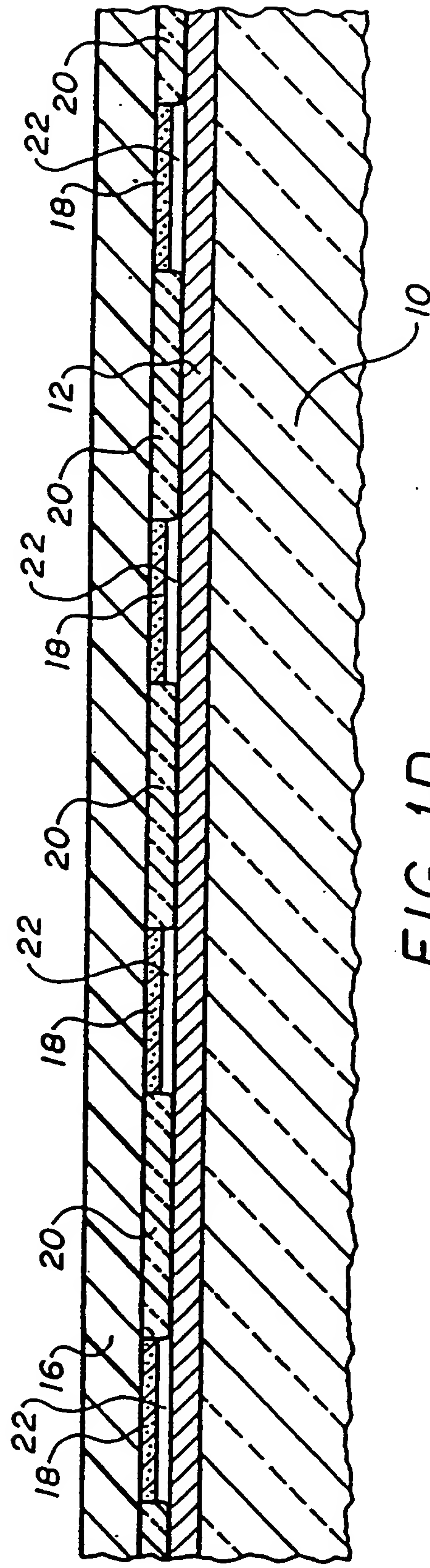


FIG. 1D

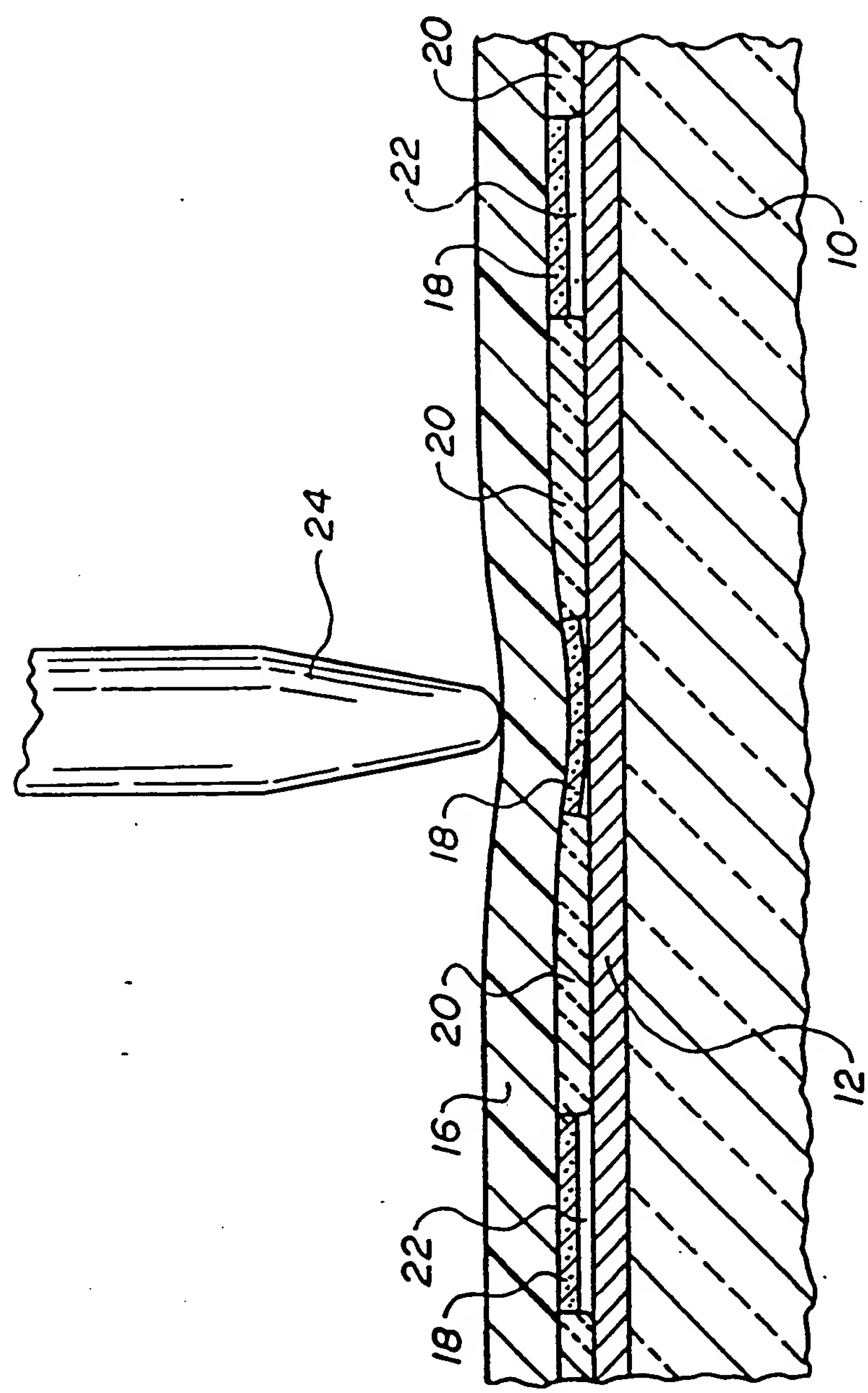


FIG. 1E

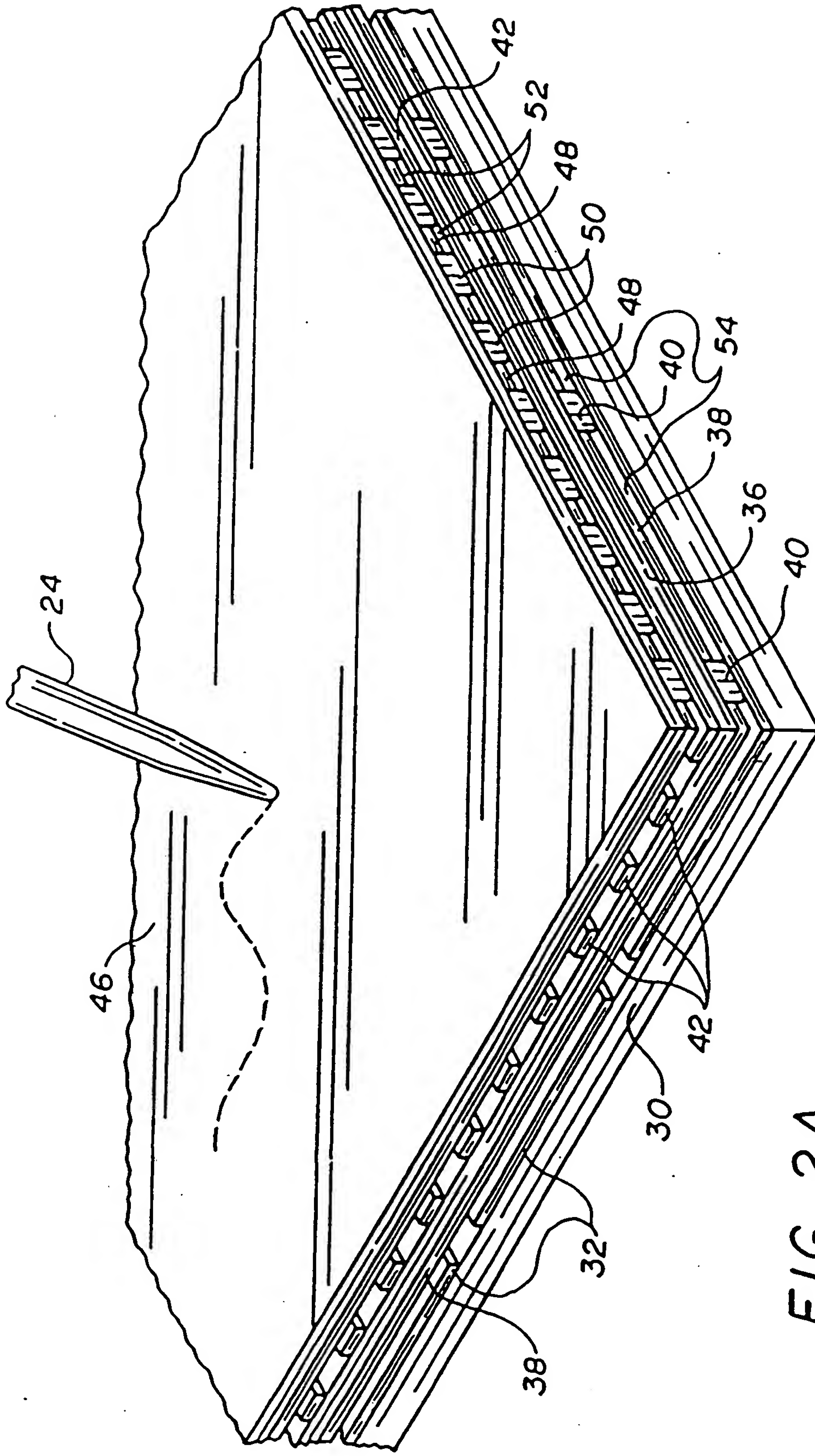


FIG. 2A

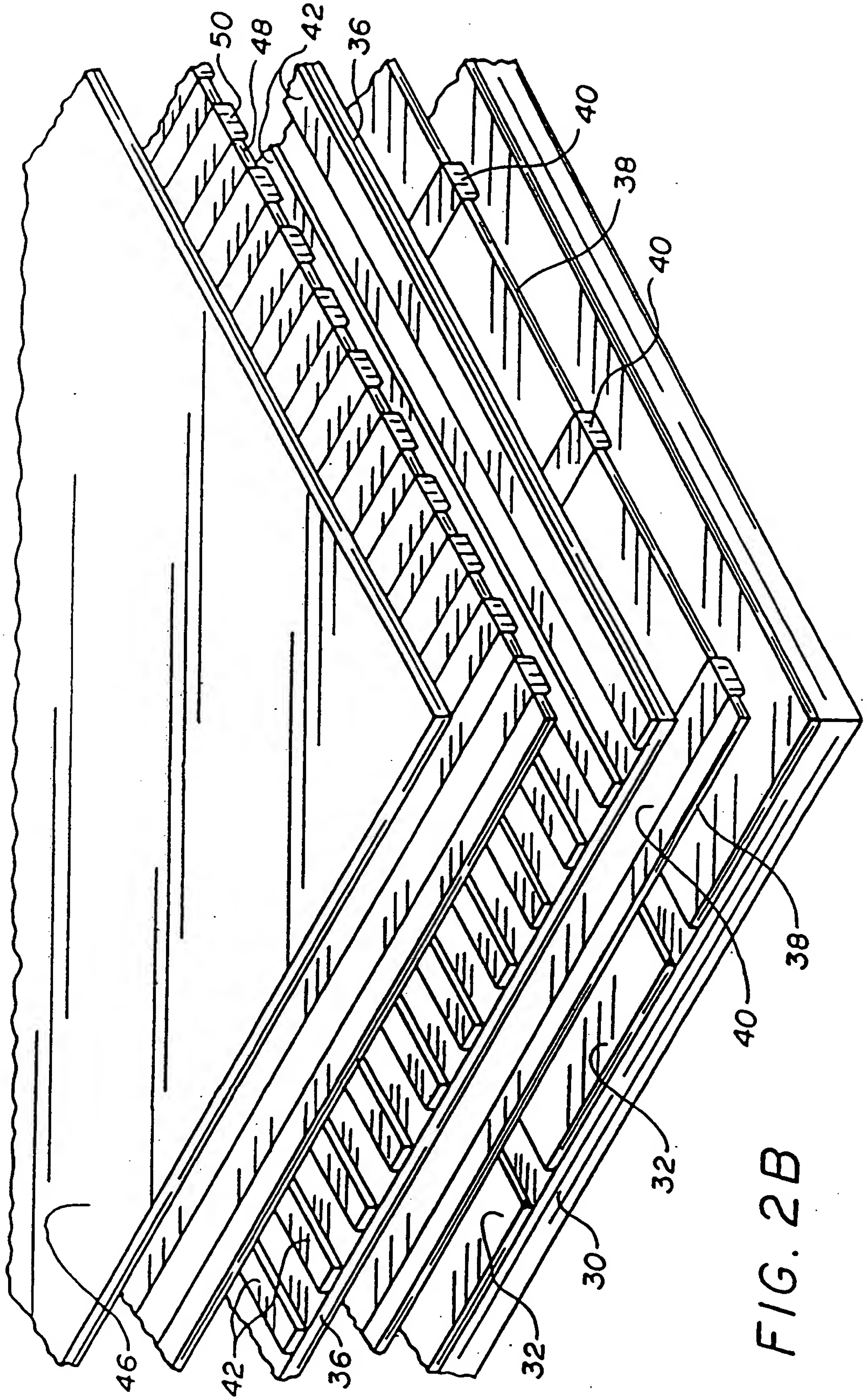


FIG. 2B

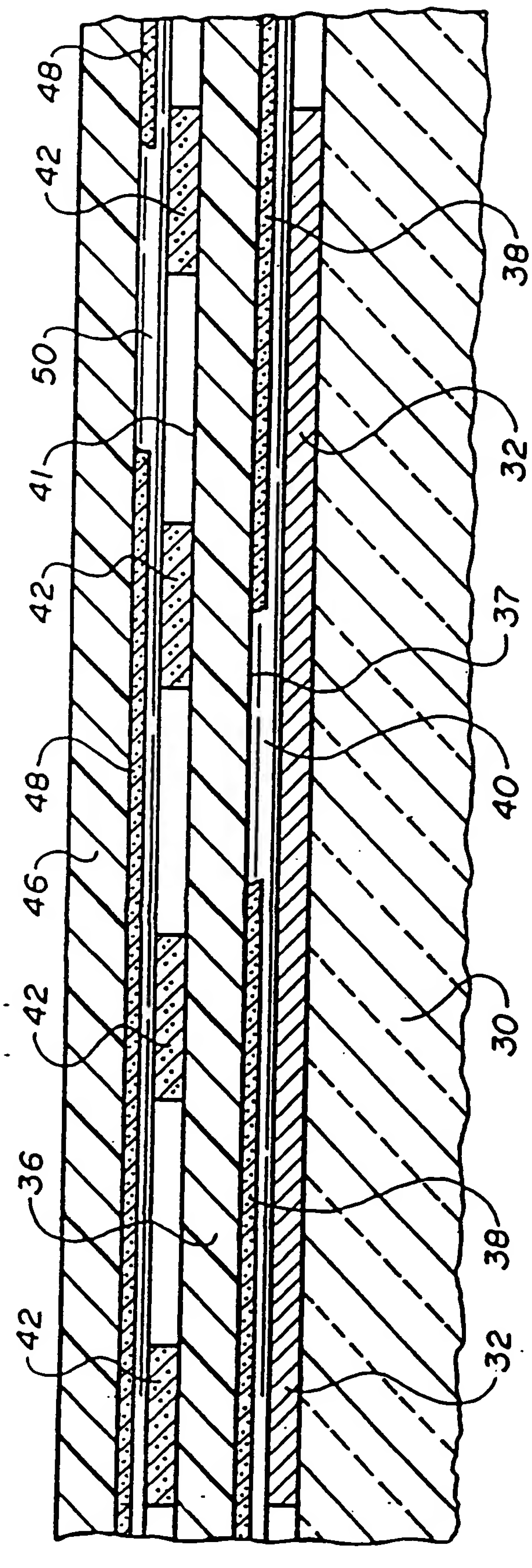


FIG. 2C

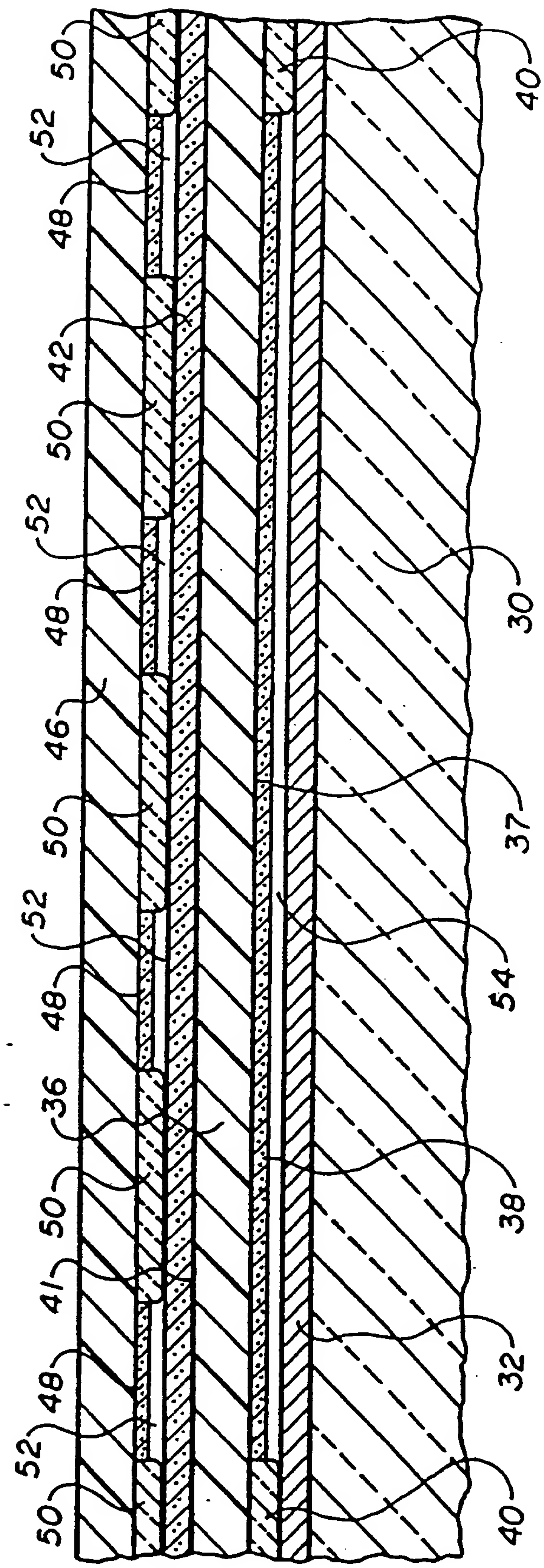


FIG. 2D

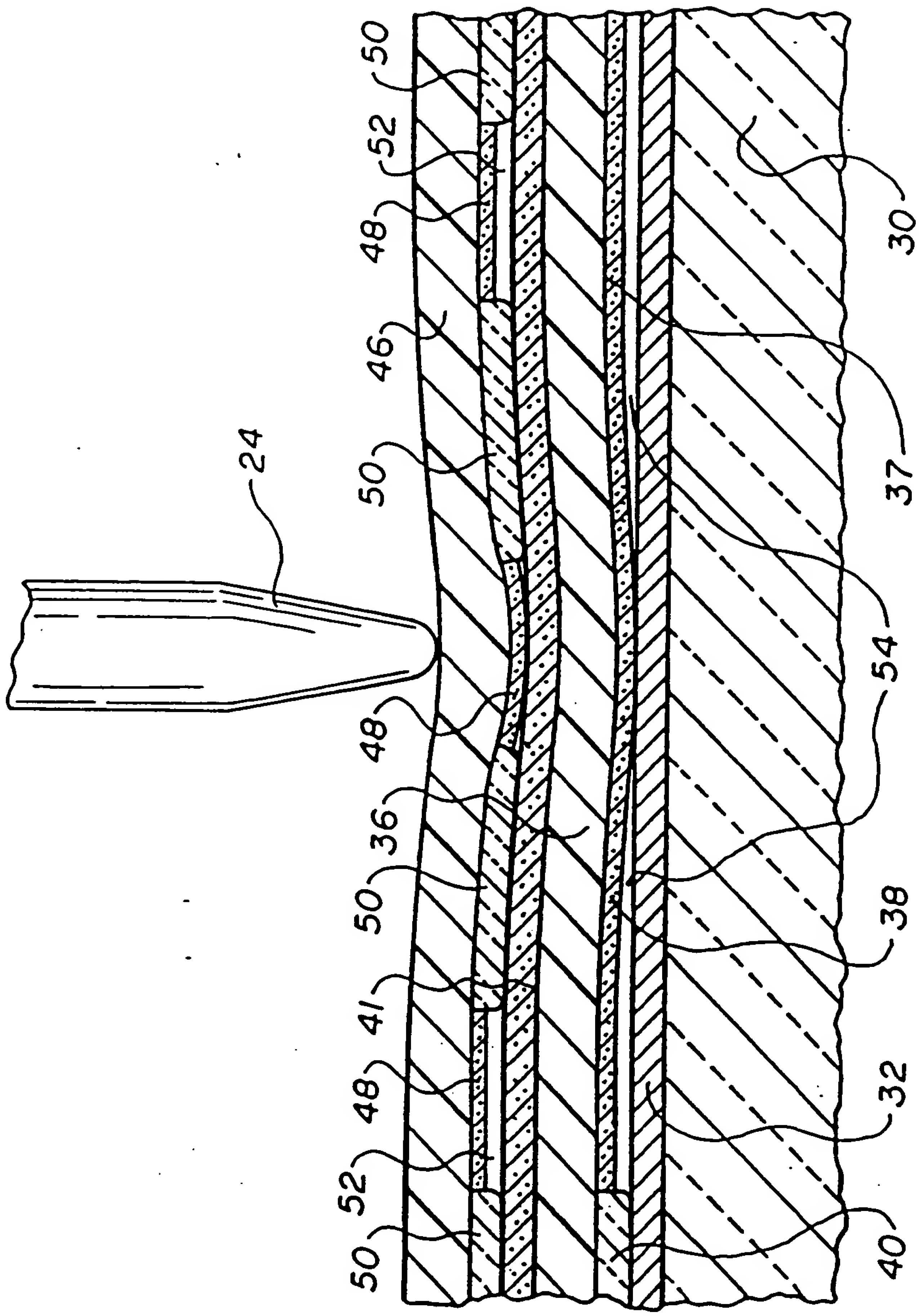


FIG. 2E

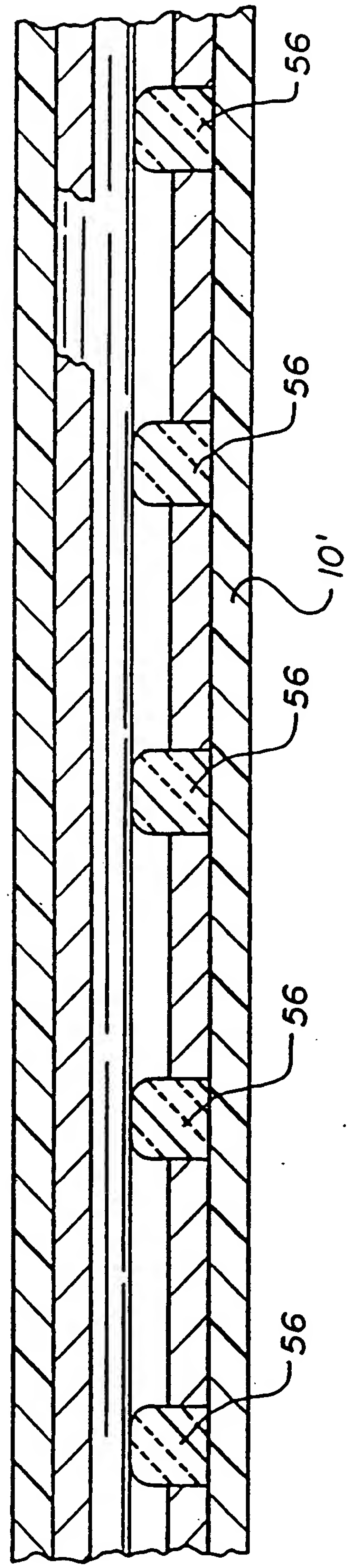


FIG. 3A

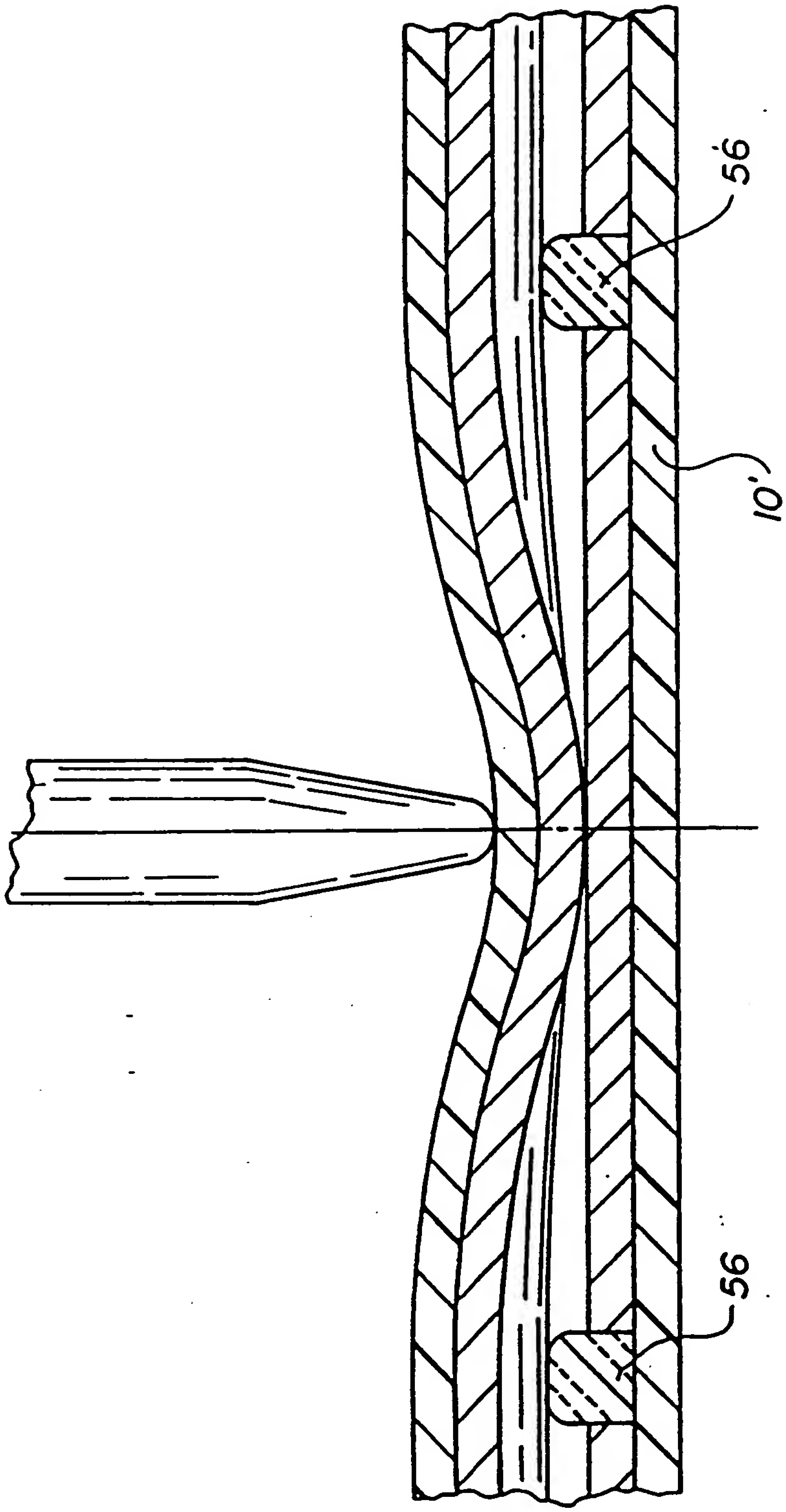


FIG. 3B

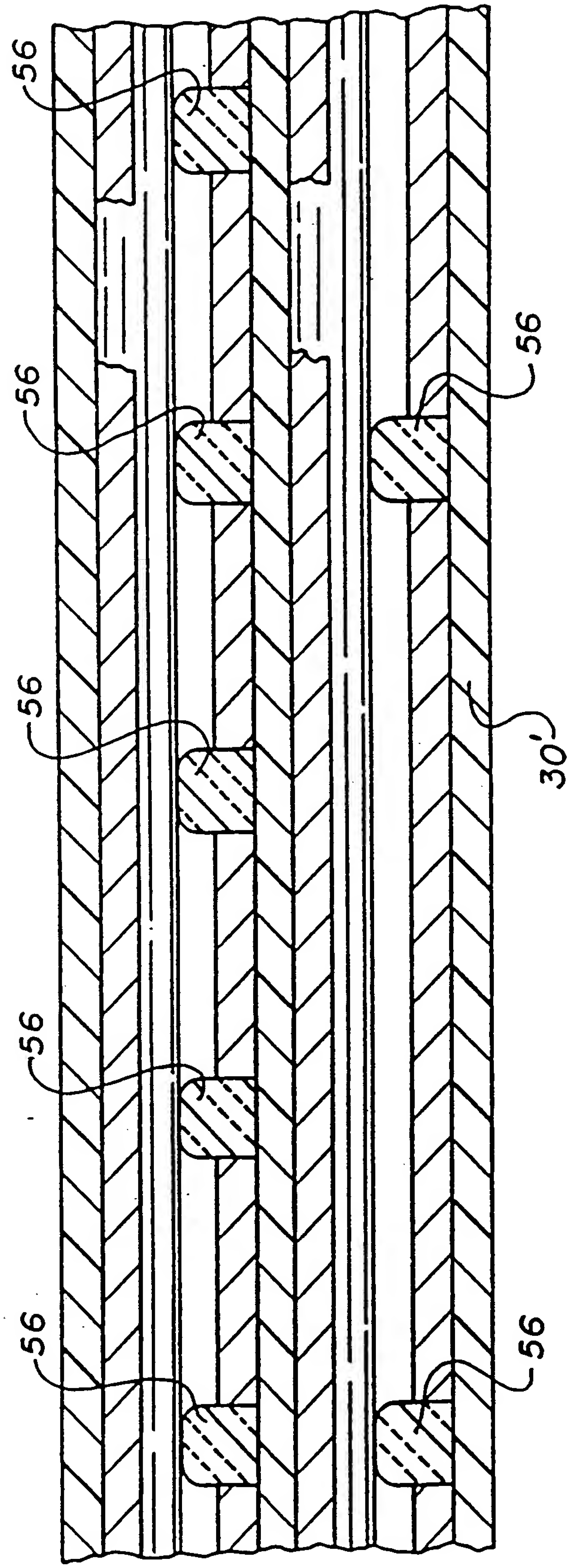


FIG. 4A

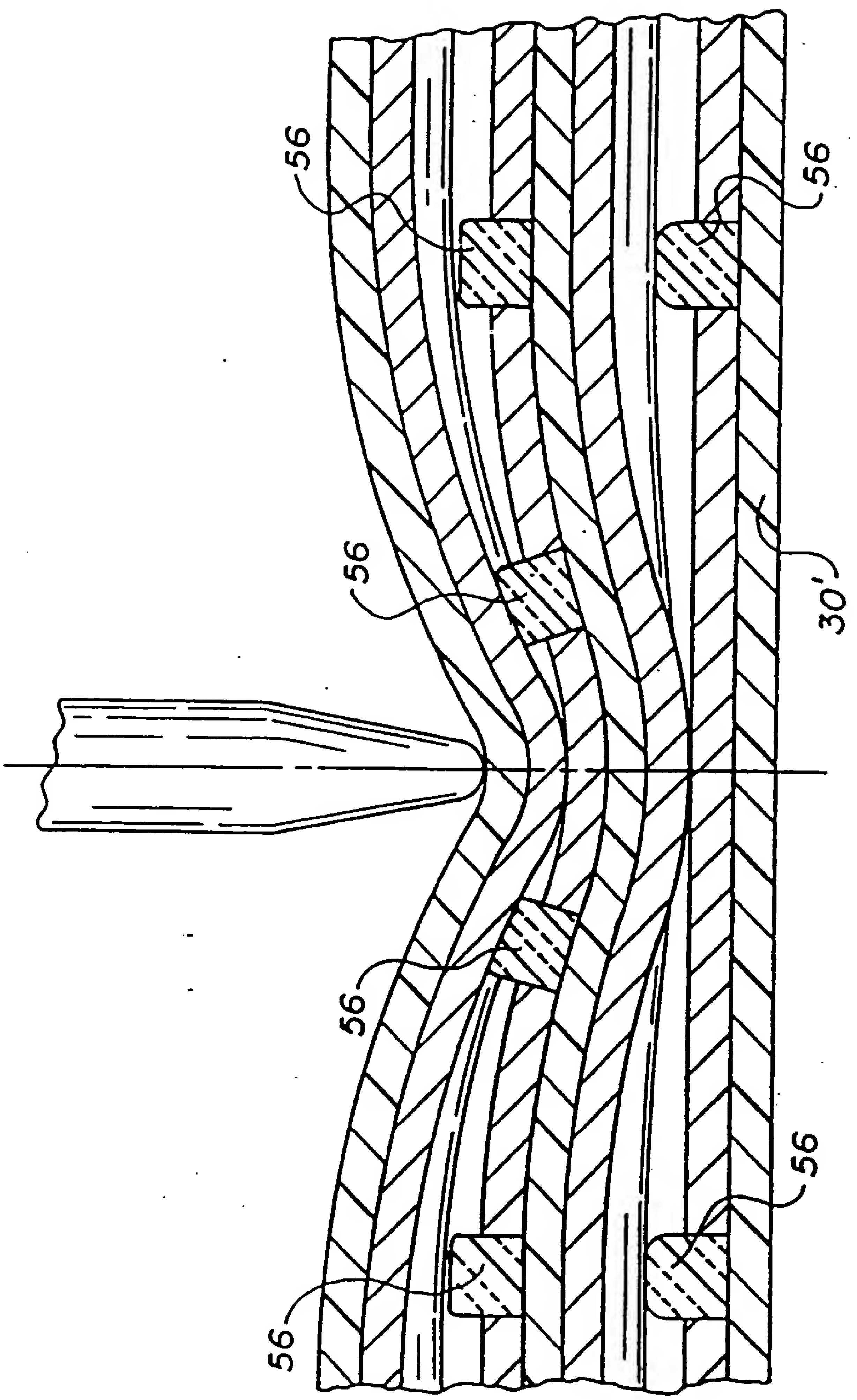


FIG. 4B

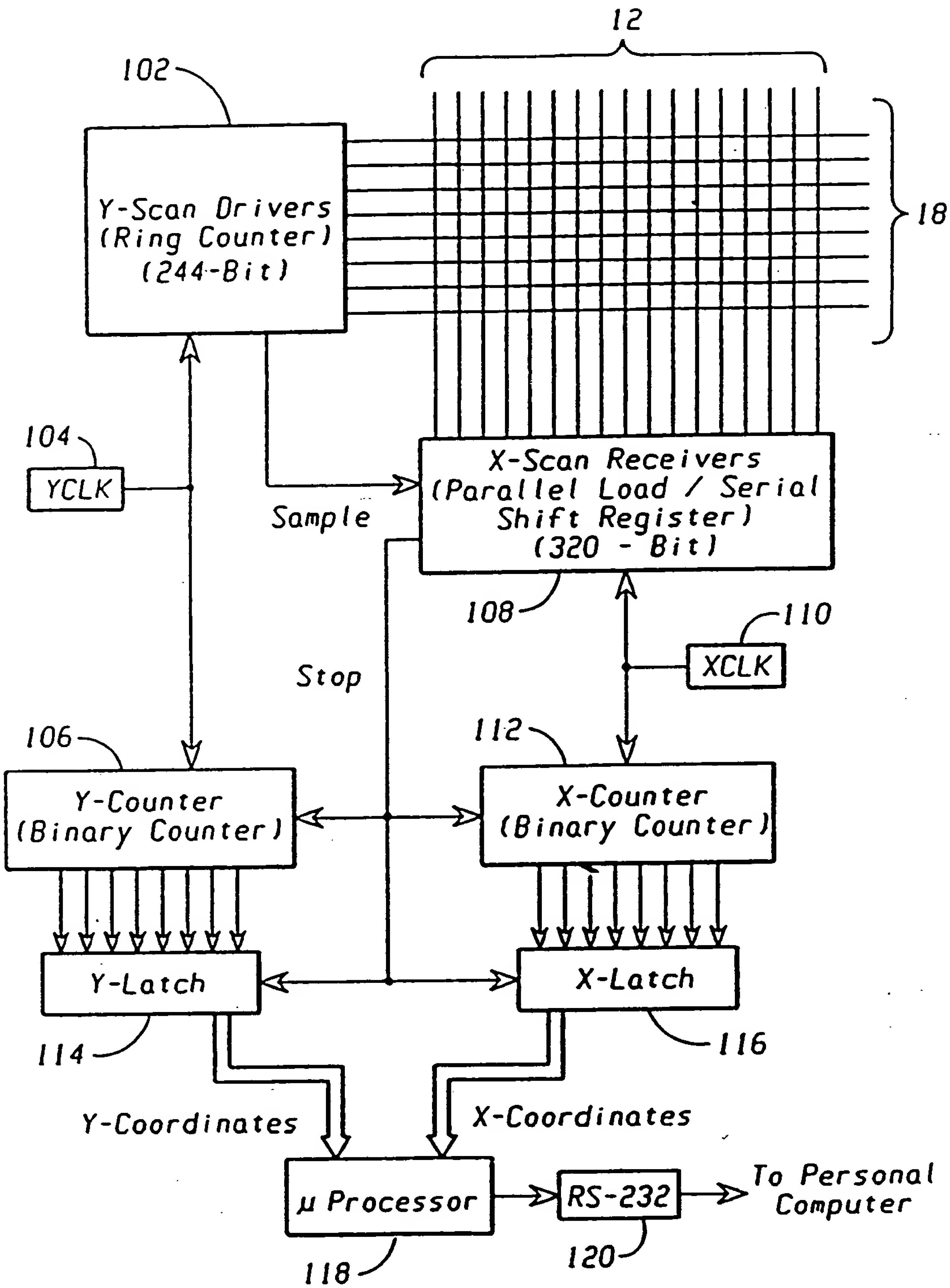
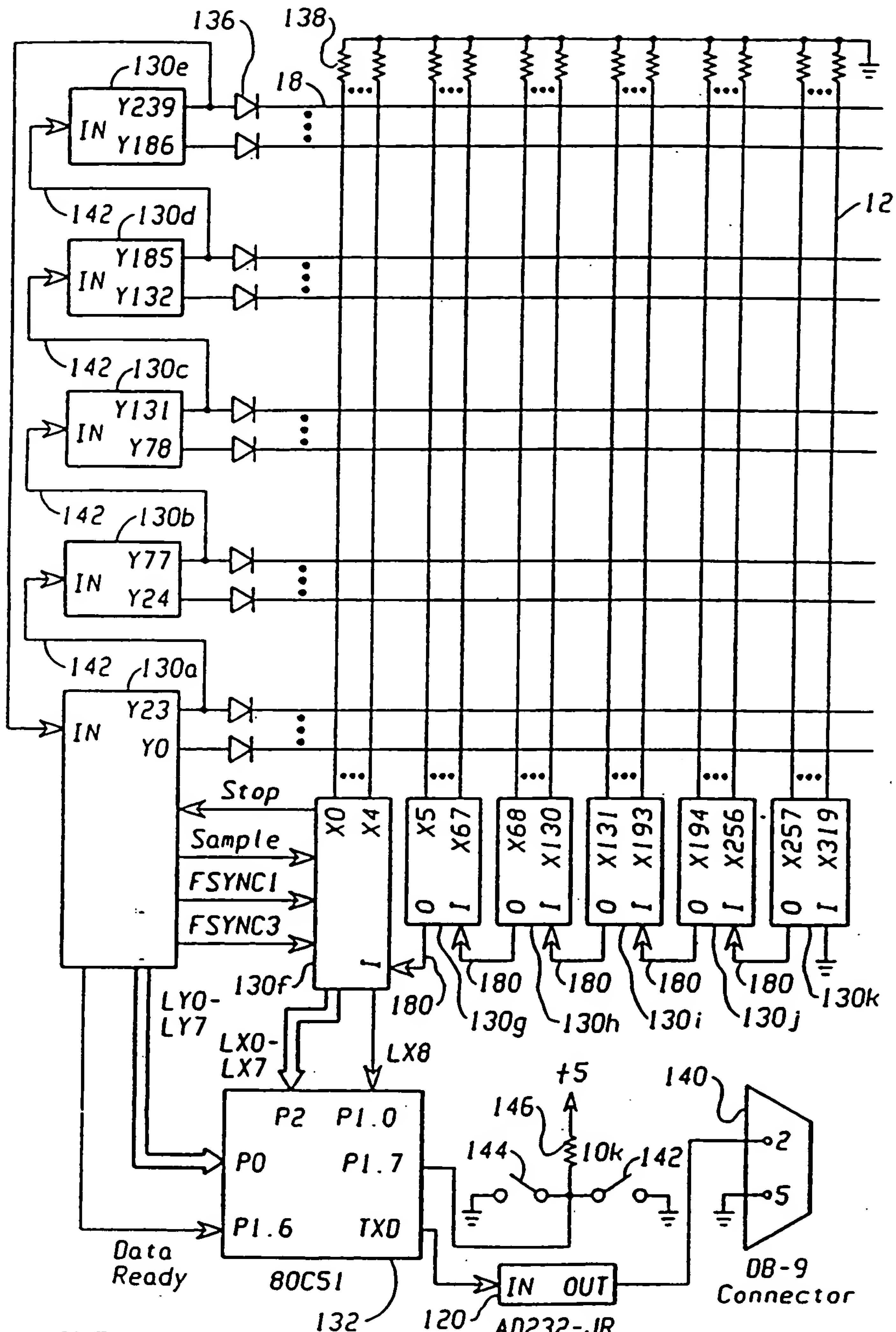

12
102
Y-Scan Drivers
(Ring Counter)
(244-Bit)
18
104
YCLK
Sample
X-Scan Receivers
(Parallel Load / Serial
Shift Register)
(320 - Bit)
108
110
XCLK
Stop
106
112
Y-Counter
(Binary Counter)
X-Counter
(Binary Counter)
Y-Latch
X-Latch
114
116
Y-Coordinates
X-Coordinates
µ Processor
RS-232
To Personal
Computer
118
120

FIG. 5A



136
138
130e
18
Y239
IN
Y186
12
142
130d
Y185
IN
Y132
142
130c
Y131
IN
Y78
142
130b
Y77
IN
Y24
142
130a
Y23
IN
Y0
Stop
Sample
FSYNC1
FSYNC3
X0
X4
X5
X67
X68
X130
X131
X193
X194
X256
X257
X319
130f
180
130g
130h
130i
130j
130k
LY0-
LY7
LX0-
LX7
LX8
+5
140
146
10k
144
142
P2
P1.0
P0
P1.7
P1.6
TXD
2
5
Data
Ready
80C51
132
IN OUT
120
AD232-JR
DB-9
Connector

FIG. 5B

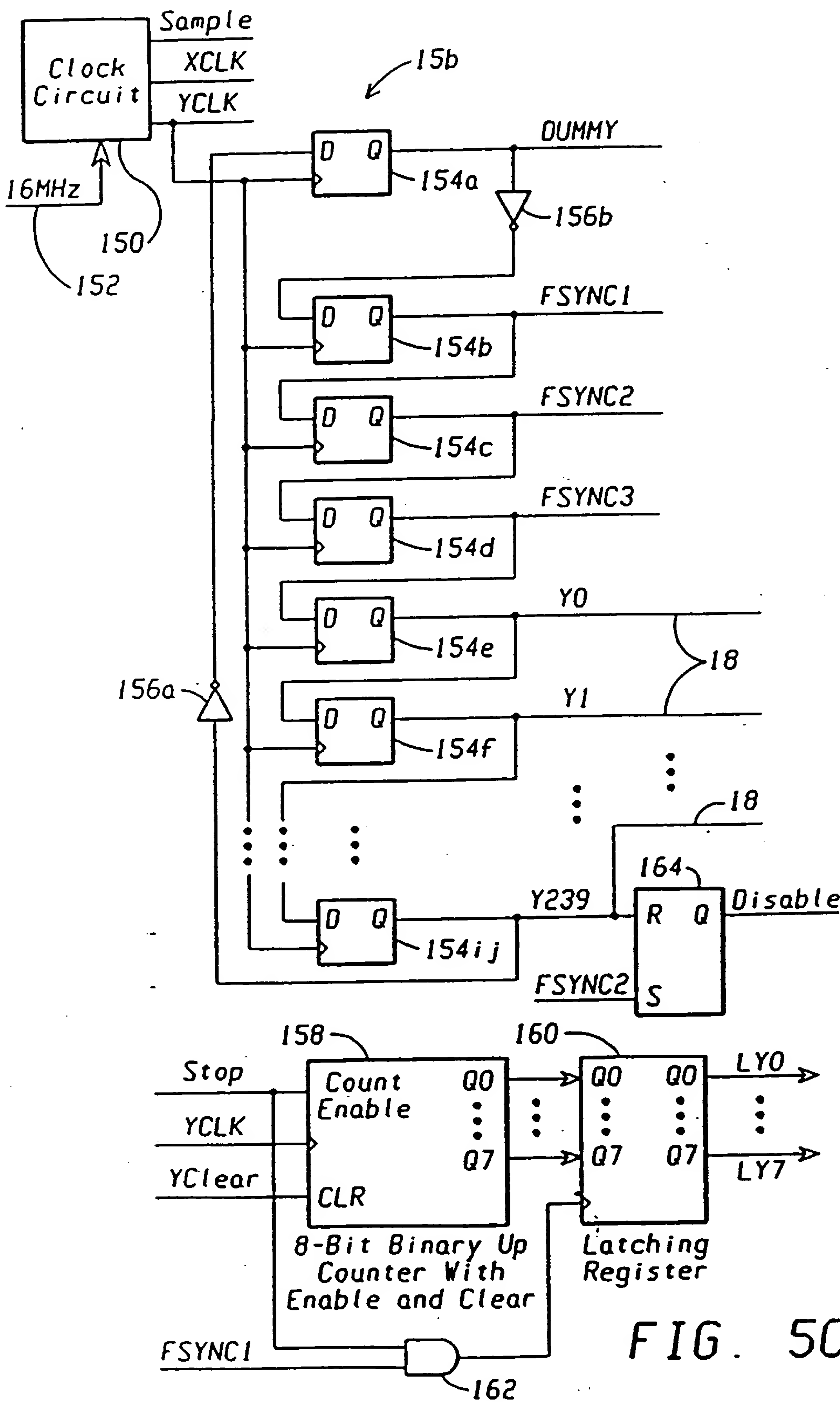

Clock Circuit
Sample
XCLK
YCLK
16MHz
150
152
15b
D Q
DUMMY
154a
156b
FSYNC1
154b
FSYNC2
154c
FSYNC3
154d
Y0
154e
18
Y1
154f
156a
18
164
Y239
R Q
Disable
154ij
FSYNC2
S
158
160
Stop
Count Enable
Q0
Q7
YCLK
YClear
CLR
Q0
Q7
LY0
LY7
8-Bit Binary Up Counter With Enable and Clear
Latching Register
FSYNC1
162

FIG. 5C

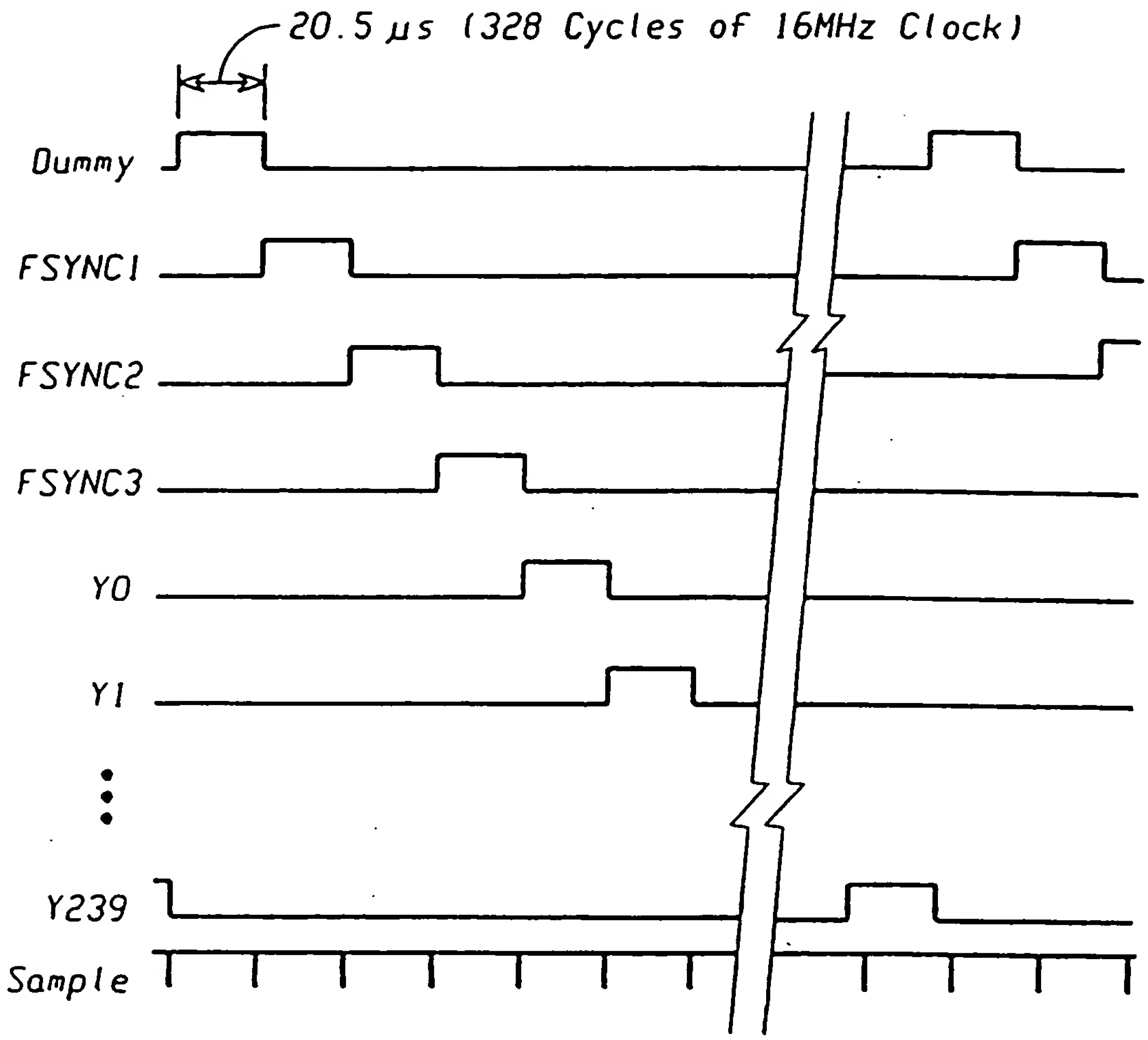

20.5 µs (328 Cycles of 16MHz Clock)
Dummy
FSYNC1
FSYNC2
FSYNC3
Y0
Y1
Y239
Sample

FIG. 5D

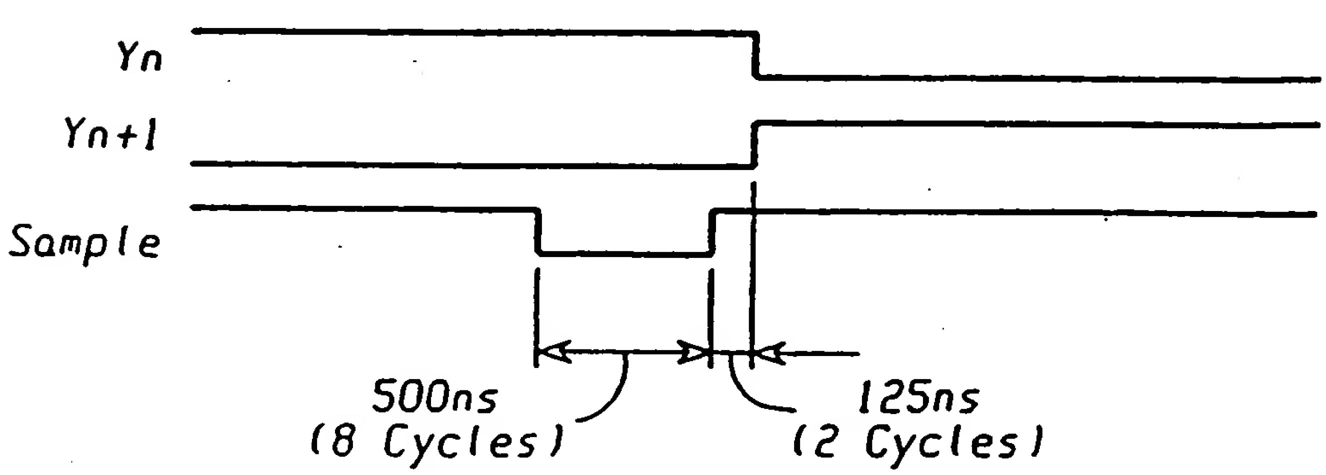

Yn
Yn+1
Sample
500ns
(8 Cycles)
125ns
(2 Cycles)

FIG. 5E

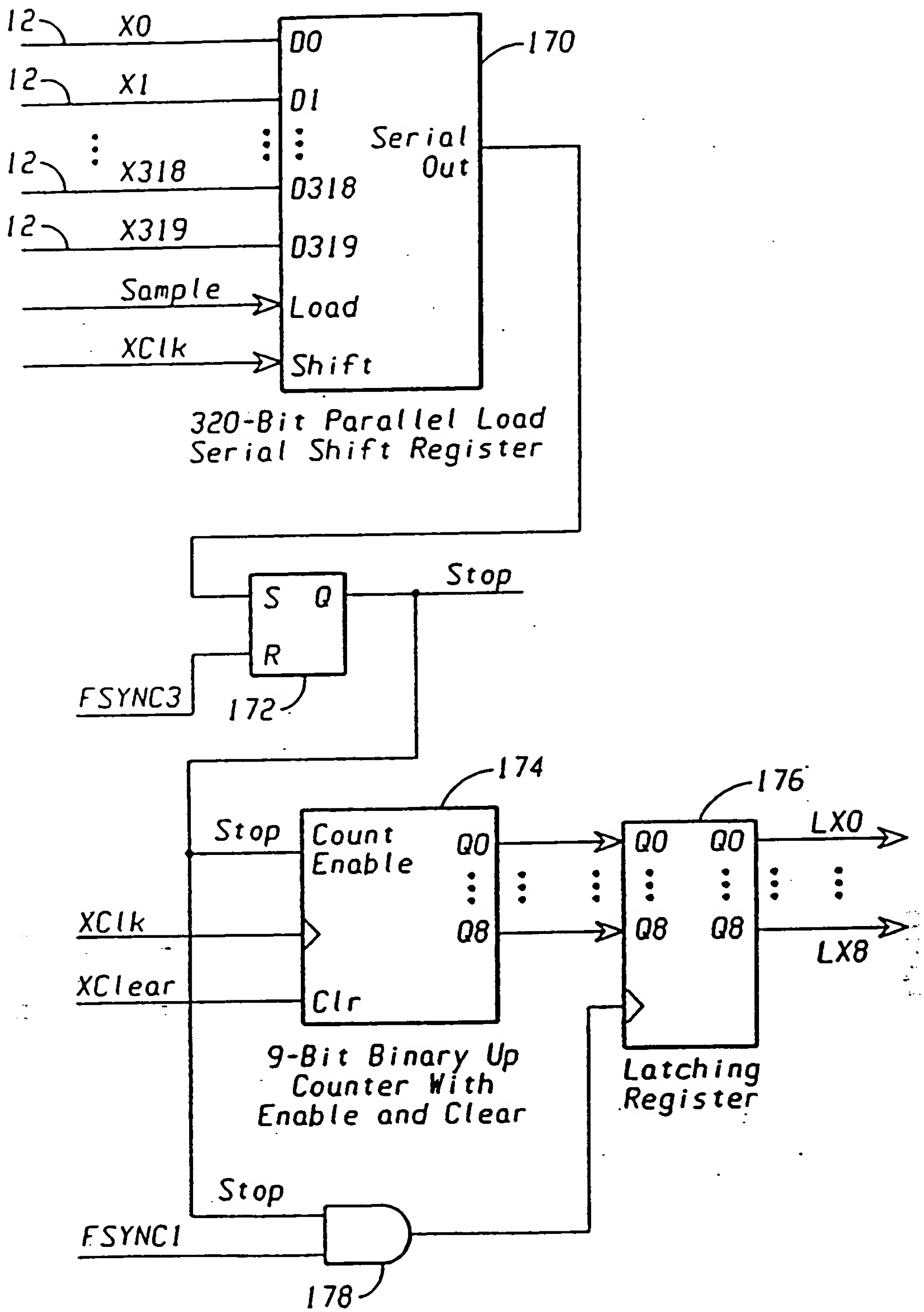
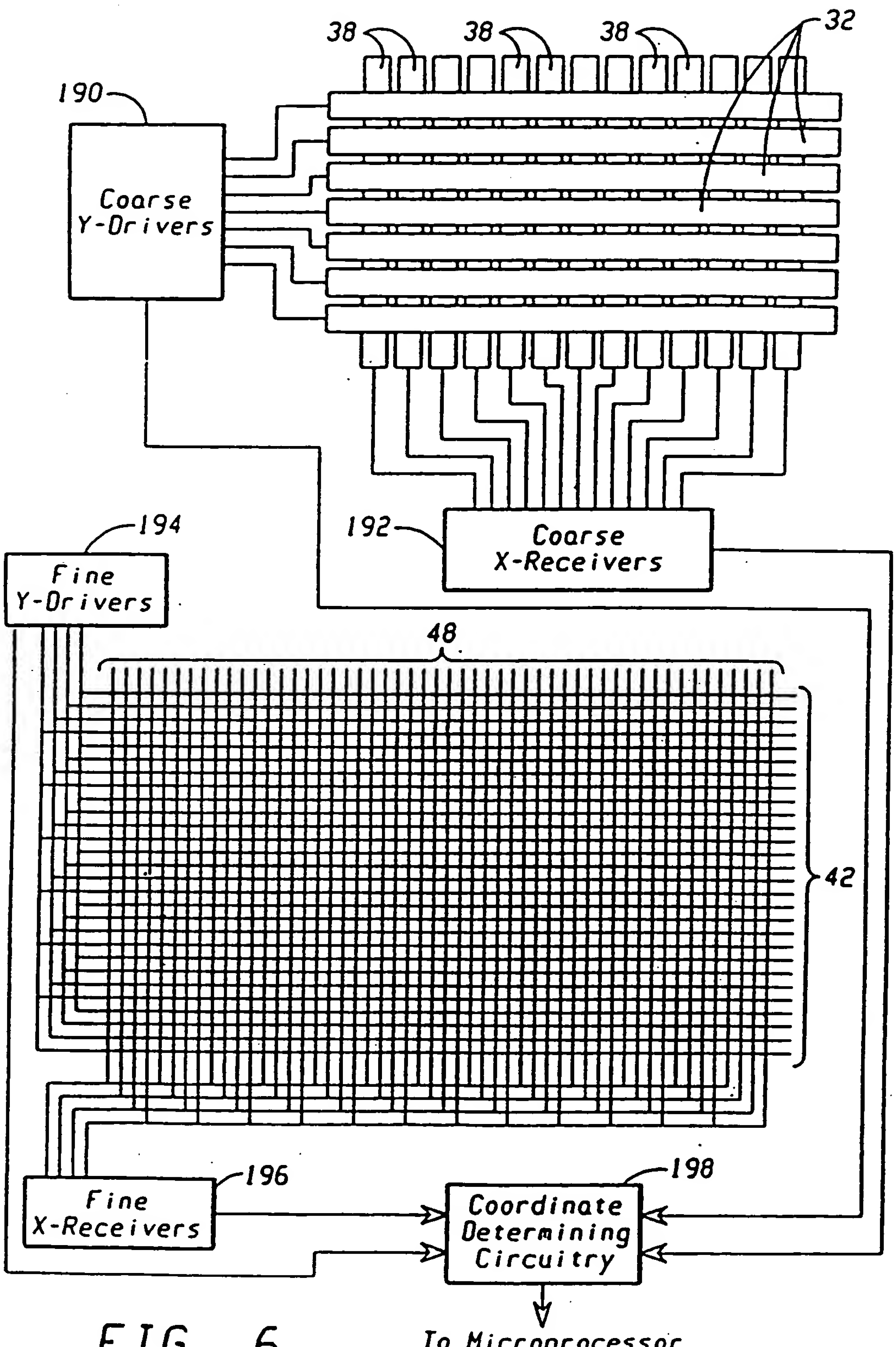

12
X0
12
X1
12
X318
12
X319
Sample
XClk
D0
D1
D318
D319
Load
Shift
Serial
Out
170
320-Bit Parallel Load
Serial Shift Register
S
Q
R
Stop
FSYNC3
172
174
Stop
Count
Enable
XClk
XClear
Clr
Q0
Q8
9-Bit Binary Up
Counter With
Enable and Clear
176
Q0
Q0
Q8
Q8
LX0
LX8
Latching
Register
Stop
FSYNC1
178

FIG. 5F



38
38
38
32
190
Coarse Y-Drivers
192
Coarse X-Receivers
194
Fine Y-Drivers
48
42
196
Fine X-Receivers
198
Coordinate Determining Circuitry
To Microprocessor

FIG. 6

FIG. 7A

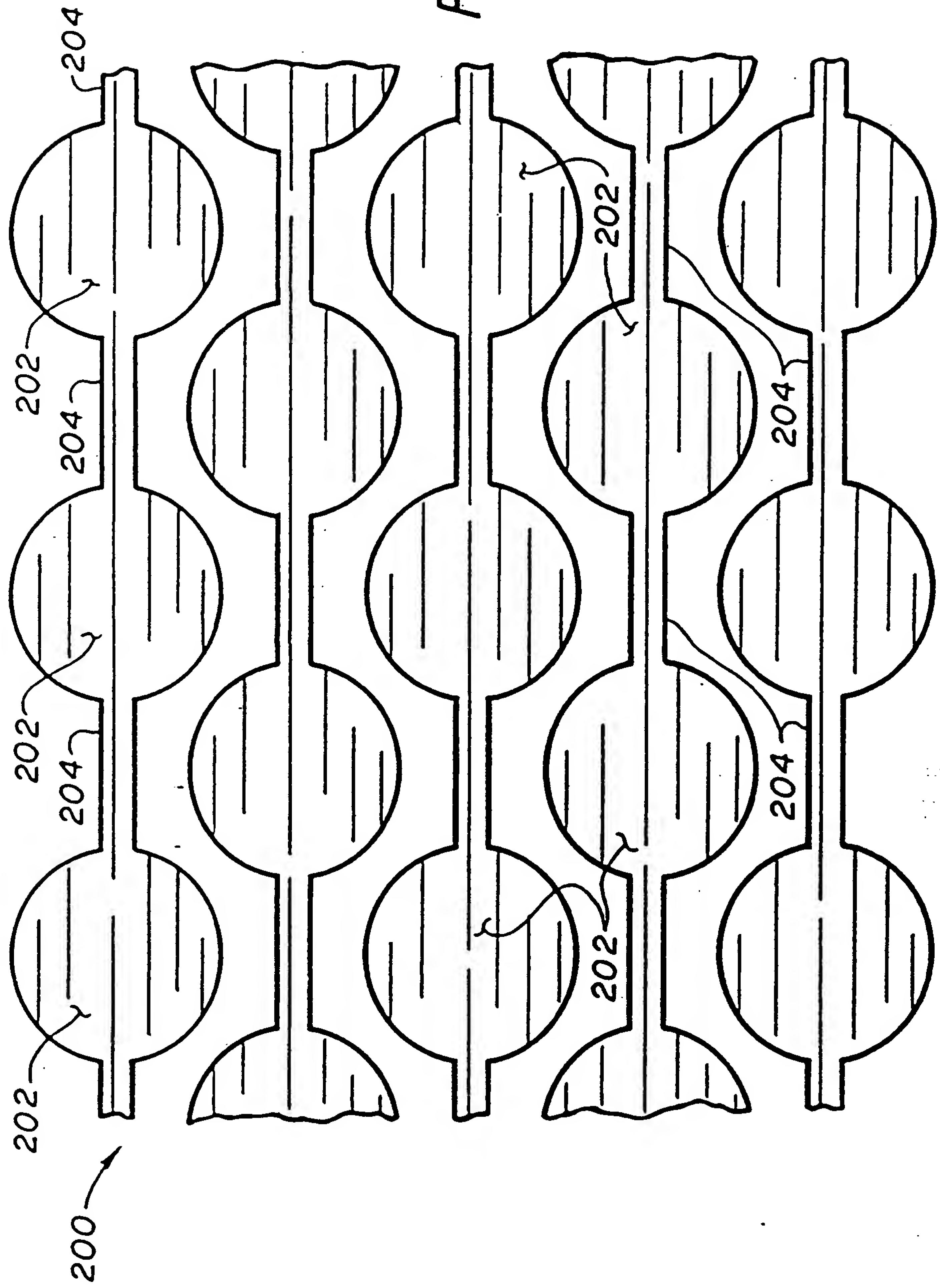
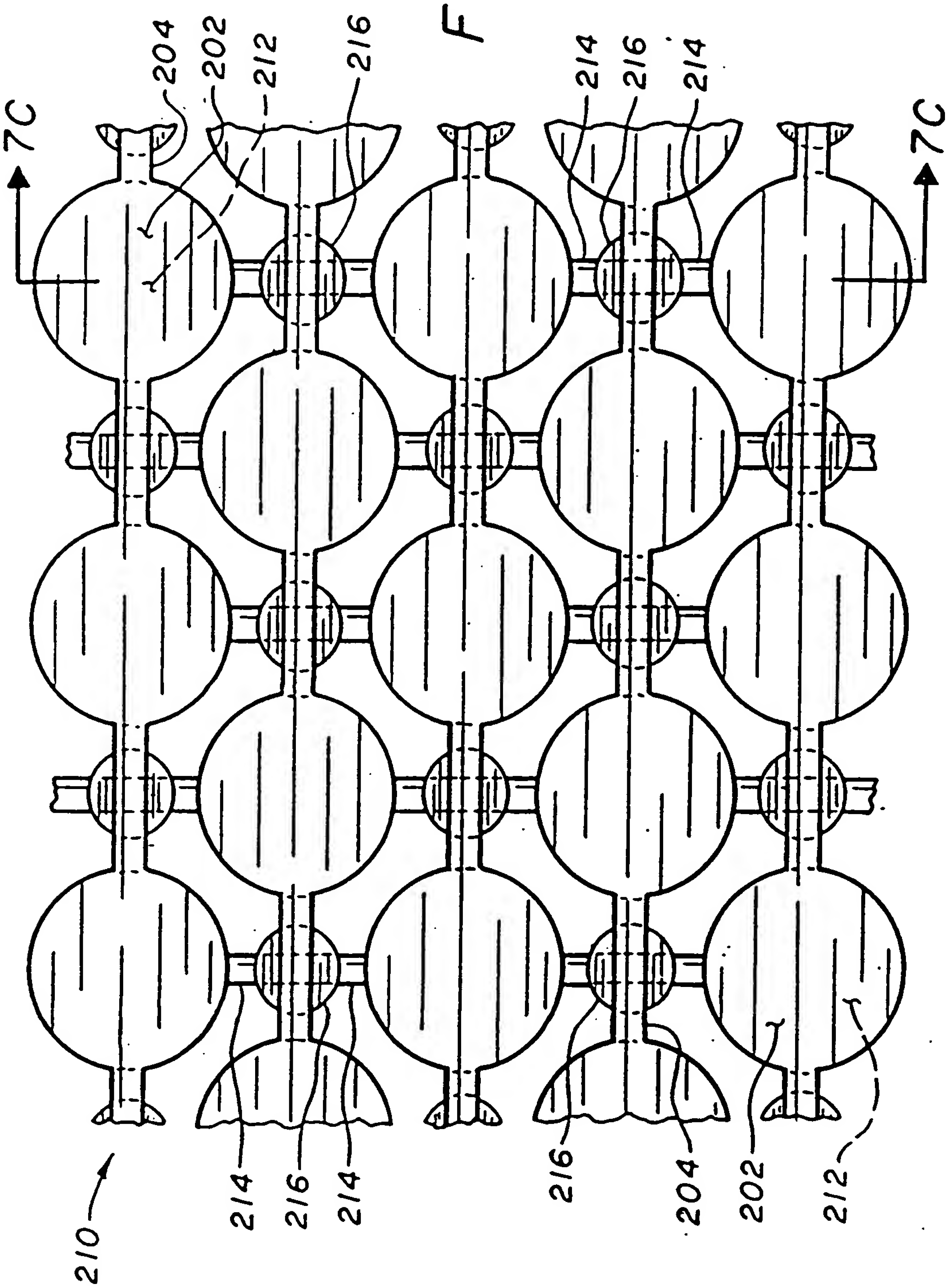


FIG. 7B



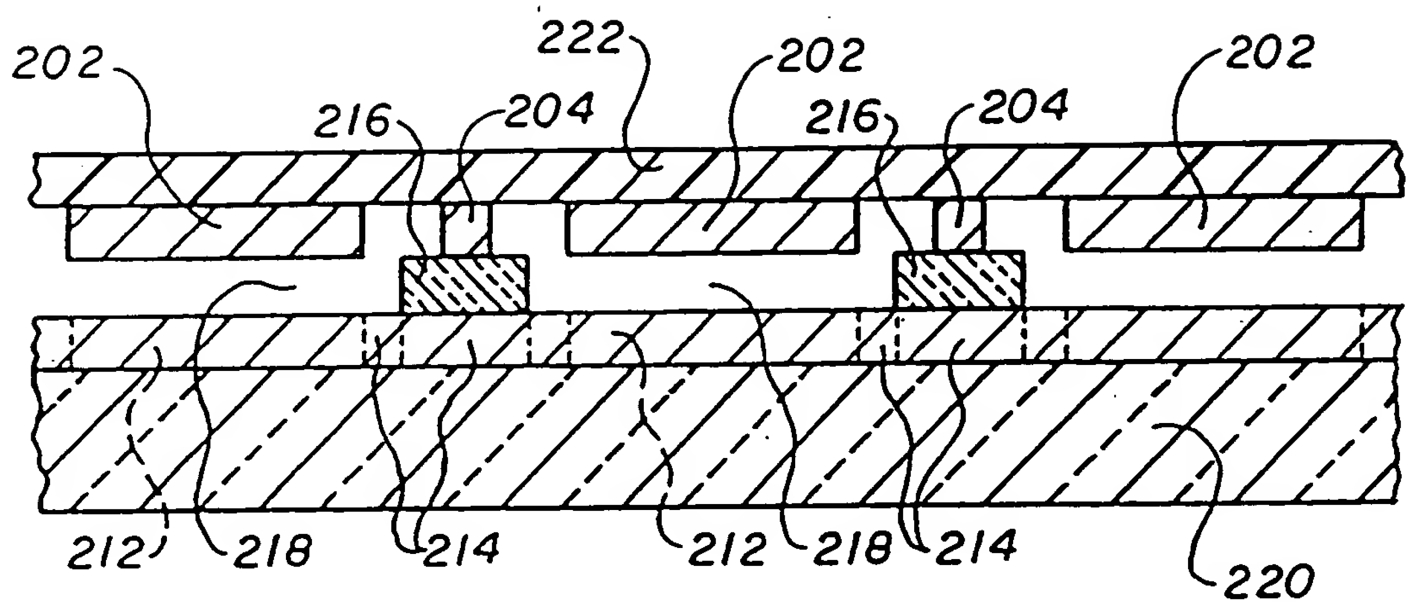


FIG. 7C

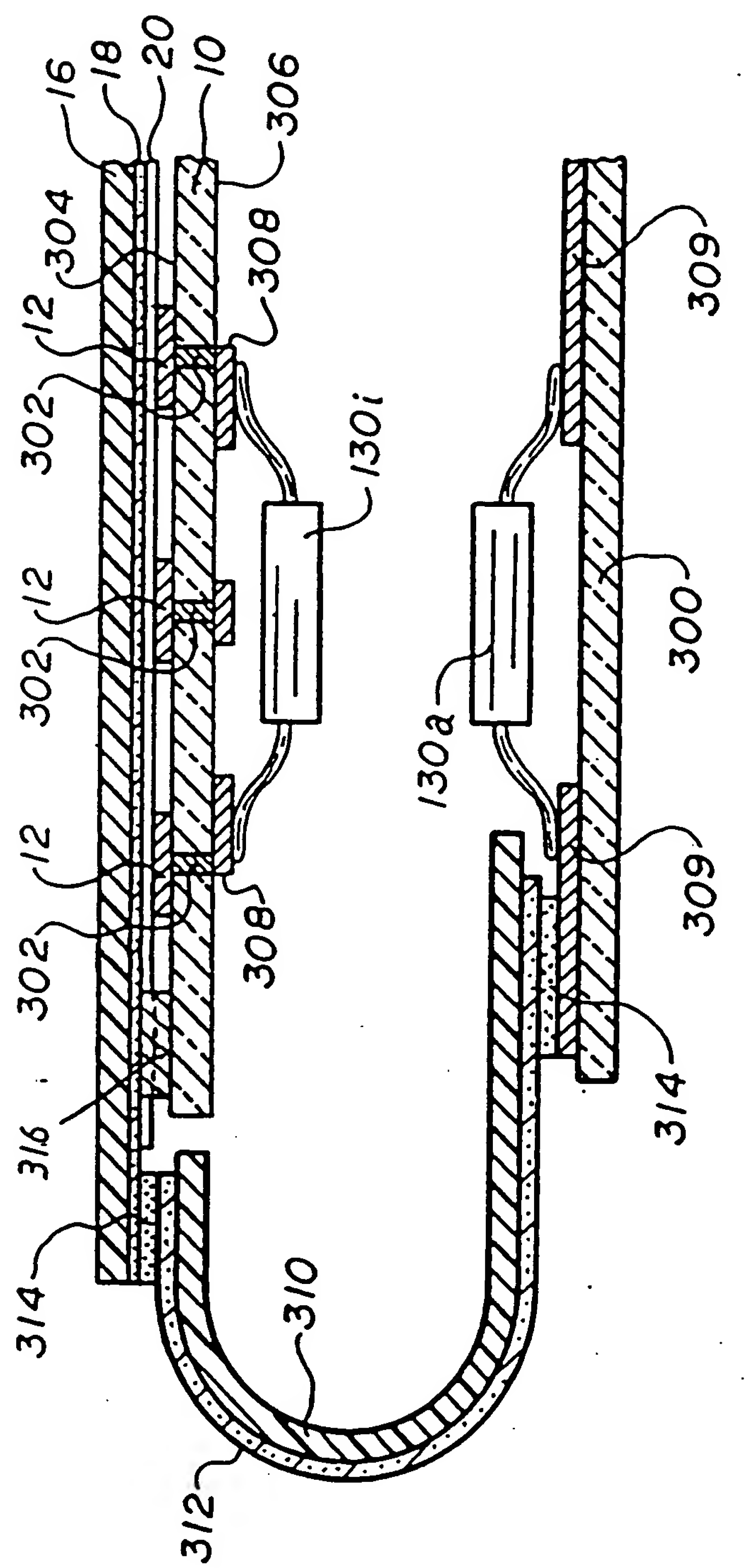

16
18
20
10
306
304
308
12
302
12
302
12
302
308
316
314
310
312
130i
130a
300
309
309
314

FIG. 8

B21

PATENT SPECIFICATION

(11) 1 314 906

DRAWINGS ATTACHED

1 314 906

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61257 31 July 1969 in

(33) Japan (JA)

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C5W 5E 8A2 8B1

G5C 31B 31G 31Q 67 68 70C

H1D 12B1 12B4 12B47Y 15B 34 35 4A4 4A7 4F1C 4F1D 4F1F 4F1G 4F1Y 4F2B 4F2C 4F2E 4F2Y 4K4 4K7 5C3 5E 5G 5S 9C 9G 9Y

(72) Inventor ISAO OTA

(54) IMPROVEMENTS IN AND RELATING TO DISPLAY DEVICES

(71) We, MATSUSHITA ELECTRIC INDUSTRIAL COMPANY LIMITED, a Japanese company, of 1006 Oaza Kadoma, Osaka-fu, Kadoma-shi, Japan, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to a display or display and recording device, hereinafter referred to, for brevity, as a display device.

The invention includes a display device comprising a layer, including a luminescent material, the luminescent appearance of the device being controllable by electrophoretic movement of an electrophoretic material in said layer.

The invention also includes a display device comprising a layer including a suspension medium and at least one material in a form susceptible of electrophoretic mobility suspended in said medium, at least one of the components of said layer being luminescent, and at least one of the components of said layer being substantially opaque to the radiation which excites the luminescence or to visible light, said suspension being bounded by opposed surfaces, spaced electrodes positioned with respect of said surfaces whereby on applying an electric field across said layer between said electrodes, the spatial distribution of said electrophoretic material between said surfaces is electrophoretically changed whereby to change the luminescent appearance to said device.

The invention makes possible a luminescent display device having a large and/or flat or curved display panel. The panel can be flexible.

Other features and advantages of the invention will be apparent from the following description of embodiments thereof, given by way of example, and the accompanying drawings, in which:—

Figures 1*a*, 1*b* and 1*c* are diagrammatic cross-sectional views of a display panel;

Figures 2*a* and 2*b* are cross-sectional views of another form of display panel;

Figures 3*a* and 3*b* are diagrammatic cross-sectional views of another form of display panel;

Figures 4*a* and 4*b* are diagrammatic cross-sectional views of another form of display panel;

Figure 5 is a diagrammatic perspective view, part broken away, of a form of display panel;

Figure 6*a* is a diagrammatic front view of an electrode for use in monogrammic character display panel;

Figure 6*b* is a diagrammatic cross-sectional view of the panel of Figure 6*a*;

Figure 6*c* is a diagrammatic front view of an alternative form of the electrode of Figure 6*a*;

Figure 7 is a diagrammatic perspective view, partially broken away, of an image display panel;

Figures 8*a*, 8*b* and 8*c* are diagrammatic cross-sectional views of an electrostatic image display panel according to this invention;

Figure 9 is a diagrammatic cross-sectional view of another form of image display device;

Figure 10 is a diagrammatic cross-sec-

tional view of an electrostatic image display;

Figure 11 is a diagrammatic cross-sectional view of a display panel;

Figures 12*a* and 12*b* are diagrammatic cross-sectional views of a form of display panel;

Figure 12*c* is a diagrammatic front view of a display panel;

Figure 13 is a diagrammatic perspective view of a member for use in the panel of Figure 12; and

Figure 14 is a diagrammatic cross-sectional view of another form of display device.

In the drawings, the size and shapes of elements are not to scale and numerous elements have been purposely distorted in size or shape for clarity.

Referring to Figure 1*a*, reference character 20 designates a luminescent display or display and recording panel which includes a luminescent electrophoretic suspension layer 21.

The suspension layer 21, in a fluid state, is contained within a housing 22 formed of a frame 23 and two opposed major housing walls 24 and 25 of material transparent to radiation flux and visible light.

The suspension layer 21 presents two opposed major surfaces extending along the surfaces of the housing walls 24 and 25. The suspension includes a dispersion of at least one electrophoretic material 26 in a finely divided powder form suspended in a suspension medium 27; the particles of the material 26 are shown greatly enlarged in this and subsequent Figures. The two surfaces of the suspension layer 2 are in contact respectively with first and second electrodes 28 and 29, which are of material transparent to radiation flux and visible light: the electrodes are attached to the inner surfaces of the housing walls 24 and 25.

The electrodes 28 and 29 are mounted to the terminals of a direct voltage source 30 through a switching means 31. If no electric field is imposed on the suspension layer from said source 30, the finely divided electrophoretic material is distributed uniformly throughout the suspending medium 27 as shown diagrammatically in Figure 1*a*.

Radiation sources 32 and 33, for example ultra-violet light sources, are positioned on opposite sides of the panel so as to direct radiation flux on both sides of the suspension layer. If the electrophoretic material 26 is luminescent and emits, for example, green light when excited by ultra-violet light and the suspension medium 27 is not luminescent and strongly absorbs the visible light and/or the radiation flux, the suspension layer 2 exhibits a deep green colour at electrodes 28 and 29 in response to the radiation.

If the deep green suspension layer is subjected to a unidirectional electric field by voltage from source 30, the electrophoretic material is caused to move electrophoretically in a direction toward the cathode or the anode, depending upon its polarity. For example, if the material is negatively charged, it moves and is deposited on the anode 28. A non-uniform spatial distribution results as shown diagrammatically in Figure 1*b*.

This different spatial distribution of the material 26 results in a luminescent appearance differing from that of the original suspension layer of uniform distribution. For example, the panel may show a bright green colour at the anode because the green light emitted in response to source 32 from the layer of the electrophoretic material deposited on the anode is directly visible through the anode 28 without transmission through and absorption by the suspension medium 27. The cathode side of the panel is dark, since light emitted from the electrophoretic material adjacent the anode is absorbed on transmission through the suspension medium. Reversal of the direction of the field by reversing the polarity of the applied voltage, causes the electrophoretic material to be deposited on the cathode 29, as shown in Figure 1*c*, and a reversal of the colour characteristic of the panel.

The foregoing description assumes that the suspension medium is not luminescent, but this may not be so, and a luminescent suspension medium can be used. In this case, the panel may exhibit, at its surfaces, colours which are additive mixtures of the luminescent colours of the medium and the electrophotoretic material. The device of Figure 1*b* or Figure 1*c* will show, at electrode 28, colours which are substantially the luminescent colours of the electrophoretic material or the suspension medium respectively. The colour characteristic of the panel depends upon the spatial distribution of the electrophoretic material, the luminescent properties of the electrophoretic material and the suspension medium and transmission properties of the electrophoretic material and the suspension medium for radiation flux and visible light. In this way, when the device is exposed to the radiation flux its luminescent appearance will change due to electrophoretic movement of the material 26.

If only a small amount of the electrophoretic material is deposited on the anode, a half-tone appearance is produced at the anode side of the panel dependent upon the amount of material deposited electrophoretically on the anode. Hence the colour characteristic at the anode side of the panel

is subject to continuous control by control of the amount of material deposited electrophoretically on the electrode, and this can be controlled by the direction, magnitude or period of application of the voltage. Since the colour at the cathode side of the panel is affected by the electrophoretic movement of the electrophoretic material toward the anode, the colour of the display panel can be changed by varying the magnitude, the duration and the polarity of the applied electric field.

Electrophoretic material deposited on an electrode surface by electrophoresis will remain on the electrode after the removal of the applied electric field, and this means that the display device described serves to record information without the sustained use of electric field or power. The panel can be restored to its original colour by an appropriate electric field of reverse polarity or by the application of strong mechanical vibrations to the device. An applied A.C. electric field to the suspension layer can also effectively restore the original colour of the panel.

With the device shown in Figure 1, changes of the luminescent appearance of the suspension layer can be observed from both sides of the panel since the radiation sources are positioned one on each side of the panel, and two walls of the housing and the two electrodes are all transparent to radiation flux and visible light. If it is desired to observe the device from one side only the other housing wall and the attached electrode can be replaced by an opaque conductive plate such as a metal plate for example, and the corresponding radiation source omitted. A suspension layer comprising a luminescent suspension medium and at least one luminescent or non-luminescent electrophoretic material suspended in the luminescent suspension medium can also be used. At least one of the components of the suspension layer, that is the suspension medium or the electrophoretic material, must be luminescent and another component must be substantially opaque to the radiation flux and/or visible light emitted from the one luminescent component. The desired opacity can be due to absorption and/or reflection of the radiation flux or visible light.

In another form of the device a radiation source is disposed behind the panel and visible light is emitted from the front. When a device of this type is observed through the electrode 28, for example, the radiation source 32 is removed and the housing wall 24 and the electrode 28 must be transparent to visible light and the housing wall 25 and the electrode 29 must be transparent to the radiation flux. The operation of such a device can be explained with reference to Figures 1*a*, 1*b* and 1*c*. If the electrophoretic material is luminescent and the suspension medium is non-luminescent and strongly absorbs light emitted from the electrophoretic material but transmits the radiation flux without substantial absorption, the brightness of the device with the same spatial distribution of the electrophoretic material as indicated in Figures 1*a*, 1*b* and 1*c* is medium, high and low, respectively. On the other hand, if the non-luminescent suspension medium does not substantially absorb the light emitted from the electrophoretic material but strongly absorbs the radiation flux, the brightness of the device in the conditions of Figures 1*a*, 1*b* and 1*c* is medium, low and high, respectively. Thus, the colour characteristic of such a device at the side opposite the radiation source can be changed by application of a suitable direct voltage. There can also be used suspension layers in which the suspension medium is also luminescent, or the electrophoretic material is non-luminescent but the suspension medium is luminescent. When there is only one luminescent component in the suspension layer another component in the suspension layer must be substantially opaque to radiation flux or visible light emitted from the luminescent component.

A device in which the radiation source is located behind the panel is useful for many display purposes as it does not require a large space in front of the panel.

The unidirectional voltage for controlling the electrophoretic material need not be a constant direct voltage and may be any other unidirectional voltage such as a pulse voltage or pulsating voltage.

The radiation flux for activating the luminescent suspension layer can be any of a number of suitable sources; in addition to ultra-violet light there can be used visible light, x-ray, γ-ray, electron beam or α-particles. Such luminescence phenomena are usually called photoluminescence, radioluminescence or cathodoluminescence, respectively. Examples of ultra-violet sources include fluorescent lamps, mercury lamps, xenon lamps or sun light.

Ultra-violet fluorescent lamps such as, for example, a lamp radiating in a range about 2537Å, chemical lamp radiating ultra-violet light of about 3000Å or a black light lamp radiating ultraviolet of about 3600Å are convenient to use. By positioning several lamps behind the display panel a relatively slim display device can be made, emitting visible light information from the front of the panel.

It is not necessary that the radiation source should be positioned outside the suspension layer, and the source can be disposed inside the layer. Radioactive isotopes

such as, for example, radium, strontium 90, tritium or promethium 147 radiate suitable flux such as α-particles or electrons. If the suspension layer includes a suitable radioactive isotope and at least one luminescent component capable of radiation visible light by the radiation flux from the isotope, the device is self-luminescent and no external source of radiation is required.

The means for activating the suspension layer is not restricted to a radiation source, and the layer can be made to emit visible light by excitation by an electric field applied across the suspension layer, that is by electroluminescence. When the electrophoretic suspension layer includes at least one component consisting of an electroluminescent material in the suspension layer, an electric field applied across the suspension layer will cause the electroluminescent material to emit visible light. The electric field for this purpose can be any suitable time-varying field, including an alternating electric field, a repetitive pulse field or a pulsating field. When the electrophoretic material consists of an electroluminescent material, the suspension layer can be made to emit light upon application of, for example, an A.C. voltage from the voltage source 30 applied between the electrodes 28 and 29 in Figure 1. An electric field applied across the suspension layer to control its brightness can change the spatial distribution of the electrophoretic material in the suspension medium established by application of the unidirectional voltage. For example, a spatial distribution of electrophoretic material such as that shown in Figures 1*b* or 1*c* established by the application of a unidirectional voltage may be destroyed by an alternating field applied from the voltage source 30, to control the brightness of the suspension layer, and change it to the distribution of electrophoretic material as indicated in Figure 1*a*. This change in the spatial distribution of the electrophoretic material depends upon the magnitude, the duration and the frequency of the alternating voltage applied. If the electrophoretic material suspended in the suspension medium follows the frequency of the applied alternating voltage to the extent of vibrating between the electrodes, the device emits light, at both electrodes, cyclically varying at the frequency of the applied voltage.

On the other hand, if the suspension layer having a spatial distribution of the electrophoretic material as shown in Figure 1*a* is subjected to, for example, repeated unidirectional pulse voltages from the voltage source 30, the negative electrophoretic material, while emitting light, moves toward an anode under the influence of the pulse voltage and is deposited on the anode surface, whereby the device emits electroluminescent light at the anode. In consequence, a device having a suspension layer in a liquid state brightened by an electric field having a direct component, cannot produce a stationary half-tone display because the applied voltage deposits all of the electrophoretic material on the one electrode. If, as described hereinafter, the suspension layer is hardened after the desired spatial distribution of the electrophoretic material is established by the unidirectional field, application of any electric voltage from the voltage source 30 across the suspension layer to control the brightness of the suspension layer can maintain the desired colour of the display without changing the spatial distribution of the electrophoretic material in the suspension medium.

The suspension layer may also consist of an electroluminescent electrophoretic material suspended in an electroluminescent suspension medium. If the colour of the light emitted by electrophoretic and suspension mediums differ in hue and/or saturation, the colour characteristic of the display can be varied over a wide range by varying the polarity of, for example, a repetitive pulse voltage applied across the suspension layer. The electroluminescent suspension medium can be prepared by, for example, suspending an electroluminescent non-electrophoretic material in non-electroluminescent suspension medium. In the present specification, the expression "suspension medium" includes not only a single phase liquid or solid medium but also a suspension comprising non-electrophoretic particles suspended in a liquid or solid medium.

The suspension medium opaque to visible light can be prepared by dissolving a coloured substance, such as a dye, in a colourless liquid, or by suspending electrically neutral coloured particles, such as dyes or pigments, in a colourless liquid. As an example, a deep blue suspension medium can be prepared by dissolving oil black dyes in ethyl acetate or kerosene.

Figures 2*a* and 2*b* show another form of display means: in these and in subsequent Figures, similar parts bear similar references. In Figure 2 a luminescent or non-luminescent porous layer is inserted in a suspension medium 36. The suspension medium 36, the porous layer 35 and the electrophoretic material 26 together make up a luminescent electrophoretic suspension layer 37. Merely to facilitate explanation, it is assumed that the suspension medium 36 is non-luminescent and transparent with respect to radiation flux and visible light. In the device of Figure 2*a*, when the device is subjected to radiation flux on both

its surfaces, a luminescent colour will be produced which is a mixture of the luminescent colour of the electrophoretic material 26 and that of the luminescent porous layer 35, if the porous layer is luminescent and the colour can be seen from both electrodes. In Figure 2 and subsequent Figures the radiation sources are omitted.

If for example the porous layer emits red light when subjected to ultra-violet light, the display device emits yellow light at both electrodes, being an additive mixture of the red luminescent light of the porous layer 35 and the green light of the electrophoretic material. If a unidirectional electric field is applied between the two electrodes 28 and 29, the electrophoretic material is caused to pass through the porous layer and to be deposited on one electrode, depending upon its polarity, for example the anode, as shown in Figure 2*b*. Also, for ease of explanation, it is further assumed that the display is observed from one side only, that is from the side of wall 24 and that the radiation is directed against that side only; in such an arrangement the housing wall 25 and electrode 29 could be replaced by an opaque electrode such as for example, a metal plate. If the layer of electrophoretic material 26 deposited on anode 28 is opaque to the radiation flux and/or the light emitted from porous layer 35, the device in the example given will show the green colour of the electrophoretic material. With a direct voltage of opposite polarity applied between electrodes 28 and 29, the electrophoretic material is caused to pass through the porous layer 35 and to be deposited on the electrode 29. If the porous layer is substantially opaque to the radiation flux and/or the light emitted from the electrophoretic material, the red light emitted from the porous layer in response to the radiation will be seen. Thus, the colour characteristic of the device can be changed from green through yellow, to red, or vice versa, depending upon the polarity of the applied direct voltage.

In another arrangement, the radiation source is arranged behind the panel, as source 33, and no radiation is directed against the wall 24, from which side the device is observed. If the porous layer 35 and the electrophoretic material 26 are opaque to radiation flux but transparent to visible light, or are opaque to visible light but transparent to radiation flux, the colour characteristic of the device can be changed from the green, through yellow to red, or vice versa, again depending upon the polarity of the applied direct voltage. It is not always necessary that the porous layer and the electrophoretic material should both be luminescent; if one at least is electroluminescent, the colour characteristic of the device can be changed by varying the polarity of a respective direct voltage pulse or a pulsating electric voltage from voltage source 30.

The porous layer 35 can be made from any luminescent or non-luminescent sheet material in which pores exist or can be produced. The pores must be of a size large enough to permit the particles of electrophoretic material to pass through but must be as small as possible to disturb the transmission of radiation flux or the light emitted from the luminescent component. Suitable materials include cloth or a mesh fabric woven of natural or artificial fibres; a fibroid sheet having thousands of irregular pores; a thin plate with a very large number of very small holes; and a sheet of material of a granular nature bonded with resin or an adhesive agent to form a porous structure.

In the construction of Figure 3*a*, a suspension medium 39 includes at least two kinds of electrophoretic materials 40 and 41 in finely divided powder form. For simplicity of description, it is assumed that the suspension medium 39 is non-luminescent and transparent to radiation flux and visible light. The suspension medium and the materials 40 and 41 together provide a luminescent electrophoretic suspension layer 42. The two materials 40 and 41 differ with respect to charge polarities and luminescent properties. It is not necessary that both of the electrophoretic materials 40 and 41 of the suspension layer should be luminescent. This device displays at its opposite sides a colour which is a mixture of the luminescent colours of the two kinds of electrophoretic materials 40 and 41 when excited by radiation flux or alternating electric field.

If a unidirectional electric field is applied to the electrophoretic suspension layer, the two electrophoretic materials 40 and 41 of different types are caused to move electrophoretically in opposite directions. The material of positive polarity moves towards the cathode and is there deposited, and that of negative polarity moves to and is deposited on the anode, as indicated in Figure 3*b*. If the material of positive polarity emits, for example, green light and the other and negative material emits, for example, red light, a spatial distribution of electrophoretic materials 40 and 41 as indicated in Figure 3*b* will result, producing a green colour at the cathode side and red colour at the anode, since the electrophoretic materials are substantially opaque to radiation flux and/or visible light.

Before the unidirectional electric field is applied the device has a yellow colour at both electrodes, due to uniform spatial distribution of the green-luminescent material

and the red-luminescent material, as indicated in Figure 3*a*.

The colour characteristic of the display or display and device can be reversed by reversing the polarity of the applied direct voltage. A device can be provided having a radiation source at one side only as described above.

In the device shown in Figures 4*a* and 4*b* an electrophoretic suspension layer 44 includes a suspension medium 39 and at least two kinds of electrophoretic materials 45 and 46 in finely divided powder form; the two materials have the same charge polarity but different electrophoretic mobilities and luminescent properties. Initially, the device of Figure 4*a* has on both sides a luminescent colour which is a mixture of the luminescent colours of the two kinds of electrophoretic materials when subjected to radiation flux or alternating electric field. If the two materials emit, for example, yellow and blue light, respectively, the device shows white colour, the additive effect of the yellow and blue light, at both sides. With an applied direct electric field both types of electrophoretic material are caused to move electrophoretically in the same direction.

If electrophoretic materials 45 and 46 are positive and the electrophoretic mobility of the material 45 is greater than that of material 46, the material 45 moves faster than material 46 in the suspension layer under the effect of the electric field and a greater amount of the former material is deposited nearer the cathode, as indicated in Figure 4*b*. The device thus exhibits a yellow colour toward the cathode and a blue colour toward the anode. This is because the electrophoretic materials 45 and 46 are substantially opaque to radiation flux and/or visible light.

The colour of the display or display and recording device can be reversed by reversing the polarity of the applied direct voltage. It will be seen that in the embodiments of the invention so far described and illustrated, the luminescent electrophoretic suspension layer comprises a suspension medium and at least one electrophoretic material in a finely divided powder form suspended in the medium. The suspension layer can comprise a porous layer and/or another electrophoretic material which may have a different luminescent property, opposite charge polarity or different electrophoretic mobility from at least one of the electrophoretic materials. The electrophoretic suspension layer includes at least one luminescent component selected from the group consisting of a suspension medium, the electrophoretic material and a porous layer. The luminescent suspension layer emits visible light when the luminescent component in the suspension layer is excited by the radiation flux or electric field such as alternating pulse or pulsating electric field, applied thereto.

The luminescent property of the suspension layer is susceptible of control by a direct electric field applied to it; the applied field changes the spatial distribution of the electrophoretic material in the suspension medium electrophoretically so that the magnitude of the radiation flux for producing a given brightness of the luminescent component in the suspension layer changes and/or the light emitted from the luminescent component in the suspension layer changes in strength and/or spectral property before the light emerges from the device. The suspension layer, therefore, must comprise at least one component which is substantially opaque with respect to the radiation flux and/or the light emitted from the luminescent component in the suspension layer. The opaque component consists of at least one component, not including the one luminescent component, and may be selected from the group consisting of the suspension medium, the electrophoretic material and the porous layer. In Figures 1 to 4, if the device is observed from one side only, for example from the side of electrode 28, the housing wall 24 and the electrode 28 must be transparent with respect to visible light. When the suspension layer is excited so as to emit light in response to the radiation flux, it is further necessary that at least one of the housing walls 24 and 25, and the electrode adjacent that wall, should be transparent to the radiation flux. It is possible to construct devices of different type by directing the radiation source toward wall 24, that is, toward the front of the panel, or toward wall 25, that is, with the source behind the panel. In any arrangement, the wall and the electrode facing the radiation source must be transparent to the radiation flux.

In Figure 5, a suspension layer 50 can be any one of the possible luminescent electrophoretic suspension layers described such as layers 21, 37, 42 or 44. The layer 50 includes at least one electrophoretic material suspended in a suspension medium and is enclosed in a housing 22 having opposite major walls 24 and 25. The first electrode 51 carries a pattern, or symbol, shown as an E-shaped symbol. The second electrode 52 extends substantially uniformly across the entire wall 24. The device is intended to be observed only from the side of wall 24, and so wall 24 and the electrode 52 are made transparent to at least visible light. If the electrophoretic suspension layer 50 is electroluminescent, the device will display the symbol 'E' upon application of, for example, a sinusoidal alternating voltage,

or an alternating or direct pulse type voltage between electrodes 51 and 52. The colour of the 'E' can be changed for example by reversing the polarity of the applied direct voltage.

When the layer 50 emits light when excited by radiation flux; the device is provided with at least one radiation source, in front of or behind the panel, and the wall and electrode attached exposed to the radiation flux must be transparent to it. The colour characteristic of the symbol can be changed, while the suspension layer is exposed to radiation flux, by varying the magnitude, duration of application or polarity of the applied direct voltage.

The construction shown in Figures *6a* and *6b* includes a luminescent electrophoretic suspension layer 50 which can be any of the electrophoretic suspension layers described, such as layers 21, 37, 42 or 44. The layer includes at least one electrophoretic material suspended in a suspension medium and is enclosed in a housing 22 having two opposite major walls 24 and 25.

A first electrode 53 is composed of a plurality of separate segmental electrodes S_1—S_7. A second electrode 52 extends uniformly over the area of wall 24. The wall and electrode through which the device is observed are transparent to at least visible light. When layer 50 is exposed to radiation flux to cause it to emit light, the wall and adjacent electrode exposed to radiation flux must be transparent to the flux. Electrodes S_1—S_7 are connected through conductive leads to electrical terminals T_1—T_7 positioned on the exposed surface of the wall 5 as shown in Figure 6b. The electrodes S_1—S_7 provide a monogrammic device, so that different combinations of the electrodes S_1—S_7 can be used to present different numbers or characters when a direct electric field is applied across the selected segmental electrodes and the second electrode 52 while the suspension layer 50 is exposed to radiation flux. For example, a direct electric field applied across the electrode 52 and the segmental electrodes S_3, S_4, S_5, S_6 and S_7 will cause the device to display a formalised figure '3'.

In another method of connecting the segmental electrodes S_1—S_7 to the respective terminals, shown in Figure 6c, the electrodes are connected to electrical terminals located on the edges of the wall 25 by using leads L_1—L_7 formed on the same surface as the segmental electrodes. Other methods of making the necessary connections can be adopted.

The construction of Figure 7 includes a suspension layer 50 which can be any of the layers described such as layers 21, 37, 42 or 44 and as such includes at least one electrophoretic material suspended in a suspension medium, enclosed in a housing 22 having major walls 24 and 25.

A first electrode consists of a series of strip electrodes x_1, x_2, x_3, . . . which are parallel to each other and are attached to the inner surface of wall 24. A second electrode is attached to the inner surface of wall 25 and consists of a further series of strip electrodes y_1, y_2, y_3, . . . parallel to each other and at right angles to electrodes x_1, x_2, x_3 . . . .

If the device is to be observed through the wall 24 the wall 24 and the adjacent electrode must be transparent to visible light. When the suspension layer 22 is excited by the radiation flux so as to emit light, the device has at least one radiation source in front of or behind the panel. The housing wall and the electrode facing toward the radiation source are transparent with respect to the radiation flux.

A unidirectional electric field is applied between one electrode of the series x_1, x_2, x_3, . . . and one of the series y_1, y_2, y_3, . . . If, for example, voltage is applied between electrodes x_2 and y_2, that part of the suspension layer 50 at the intersection electrodes x_2 and y_2 is subjected to the field and forms one picture element. The narrower the strip electrodes, the smaller the picture elements thus formed.

More than one electrode can be selected from each series to enable a desired pattern of picture elements to be built up. Scanning techniques can be utilized to scan the picture elements sequentially and cyclically.

The desired series of strip or segmental electrodes as shown in Figures 5, 6 and 7, can be prepared by any suitable method, such as electrodeposition, vacuum evaporation, printing or photoetching techniques.

Another embodiment of the invention is shown in Figures *8a*, *8b* and 8c. This includes a suspension layer 50, which can be any of the layers previously described. The layer includes at least one electrophoretic material suspended in a suspension medium and is enclosed in a housing 22 having spaced walls 55 and 56; at least one wall, in this case wall 55, consists of a sheet of an insulating material such as polyester, cellulose acetate, cellophane or polyethylene.

An electrode 57 is placed on the outer surface of the wall 55; it is not fixed to the surface of the wall and can be easily removed. The electrode is, however, coupled to the suspension layer 50. The second electrode can be, for example, a metal plate and as shown is constituted by the other wall 56 of the housing.

If the second wall has a high electrical resistance, a second electrode can take the form of a thin electrically conductive film

attached to the inner surface of the wall 56; again, it is also possible to use as the electrode, a metal plate on which the wall 56 is placed. If the wall 55 has a high electrical resistance, a higher value of direct voltage must be impressed between the electrodes.

The contact area of the first electrode 57 can be given a pattern, and when a direct electric field is applied corresponding patterns are produced on the surfaces of walls 55 and 56 due to the movement of the electrophoretic material, and this pattern will persist after removal of electrode 57. The wall of the housing through which the effect is observed must be transparent to visible light and the wall exposed to radiation flux must be transparent to it.

The electrode 57 can be a manipulable electrode, such as a pen-like electrode, capable of being moved freely over the surface of wall 55 and it is then possible to produce a desired pattern, or writing, on the surface of the wall by applying voltage between the pen electrode and electrode at 56, while the electrode 57 is moved.

The desired electric field across the suspension layer 50 can be produced by surface charging of the high resistance wall 55, using charged particles such as ions or electrons in a manner similar to that used in electrostatic recording.

To erase the electrostatic patterns, a roller having a conductive surface can be used, with alternating or direct voltage applied to it, the roller being moved over the insulating surface of the wall. Alternatively, positive or negative charged particles can be put on the surface of the wall to produce the erasing electric field.

It is preferred to insert between walls 55 and 56 a spacer such as a porous layer 58, as shown in Figure 8*b*, or a sheet 59 having a large number of projections, as shown in Figure 8*c*, particularly when the walls are of flexible material. Said spacer is substantially transparent to visible light and radiation flux and serves to keep the walls 55 and 56 apart, and preserve the desired thickness of layer 50 despite pressure applied to the wall of the housing, due to the pressure of the electrode 57 or to bending of the housing, where the electrophoretic suspension layer is in liquid form.

The spacer can be made from any sheet having pores or projections and suitable material is a screen made of nylon or Tetron: Tetron is a trade name of a polyester fibre available in Japan. The porous layer 35 in Figure 2a must be substantially opaque or luminescent, but the spacer 58 or 59 is substantially transparent and non-luminescent and may act as a mechanical spacer between major walls of the housing. The spacer can be merely inserted between the two walls, or one or both surfaces of the spacer can be attached to the surface of the adjacent wall. The spacer need not be inserted in a suspension layer which includes a porous layer such as 35, if that layer is capable of serving as a spacer between walls of the housing.

Another form of construction is shown in Figure 9. Housing 22 has an insulating wall 55 and a wall 25 to which is attached an electrode 29, connected to a voltage source 30. Wall 25 and electrode 29 are transparent to at least visible light. Housing 22 contains the electrophoretic suspension layer 50 and the housing is designed to form the front face of the envelope 60 of a cathode ray tube device.

The device includes an electron gun 61 and scanning means 62, by which negative electron charges ~~in a given~~ pattern can be deposited on the insulating surface of the wall 55. By modulating the beam intensity, for example in accordance with a video signal, the charge pattern built up will produce a corresponding electric field across the electrophoretic layer 50. When the suspension layer is exposed to radiation flux, visible patterns are reproduced on the walls 25 and 55 due to the movement of the electrophoretic material. Conveniently the radiation flux can be directed onto the suspension layer through a transparent window 63 in the envelope and through wall 55, or through the wall 25 and electrode 29. In the latter case, if the electrode 29 and wall 25 are transparent to radiation flux and to visible light, the window is not necessary. The first electrode 29 acts as an anode, and the electron gun 61 acts as a cathode. The visible pattern can be erased by a suitable secondary emission characteristic of wall 55.

In a modification of the display device shown in Figure 9 the wall 55 is replaced by a wire-mosaic faceplate consisting of a thin glass sheet having embedded therein a large number of fine transversely extending wires. This wire-mosaic provides the electrical connection between the electron beam in the vacuum and the electrophoretic suspension layer outside the vacum. The electron beam charges the wires of the mosaic and so applies an input electric field across the suspension layer.

Figure 10 shows an arrangement including the suspension layer 50 which can take any of the forms described. The layer includes at least one electrophoretic material suspended in a suspension medium and is applied to a base plate or sheet 65 which can be of material such as paper, metal or plastic. The base plate is placed on an electrode 66. Since the suspension layer is not confined within a housing, it must have high viscosity, but must be capable of being brought to a condition in which the re-

quisite degree of electrophoteric mobility is possible when voltage is applied. A suitable suspension layer may be in a solid state at room temperature but capable of being softened by a suitable method, such as heating or the addition of a solvent.

An electrode 57 is shaped to give a desired pattern of contact with the surface of the suspension layer. A direct electric field is applied between the electrodes so as to move the electrophoretic material electrophoretically while the suspension layer is softened by heat or by means of a solvent. The suspension layer is exposed to radiation flux and when thereafter the electrode 57 is removed the pattern remains on the surface of the suspension layer. If the base plate is transparent, a complementary pattern of different colour can be observed through the base plate. A permanent pattern can be produced by cooling the suspension layer or by evaporating the solvent as the case may be. If the base plate 65 is conductive, it may be used as the electrode, and a separate electrode 66 is not required.

The luminescent component in the luminescent electrophoretic suspension layer can be a fluorescent material of the type used in fluorescent lamps, scintillators, cathode ray tubes, radar or luminous paints.

The luminescent electrophoretic material can be organic or inorganic fluorescent materials in a finely divided powder form; fluorescent pigments or dyes can be used directly. Fluorescent material which can be used include material in the form of a main body consisting of the oxide, sulphide, selenide, silicate, phosphate or tungstate of metal such as calcium, barium, magnesium, zinc, cadmium or strontium. A small amount of manganese, silver, copper, antimony, lead or bismuth is added, as an activator, to the main body. Organic fluorescent materials which can be used include dyes such as diaminostilbene group, fluorescein, thioflavine, eosine or rhodamine B.

The luminescent appearance of the material refers to the intensity and/or spectral distribution and persistence of the light emitted from the luminescent material in response to radiation flux or electric field applied thereto. Suitable luminescent suspension medium can be prepared by dissolving the fluorescent dye in a liquid carrier or by suspending electrically neutral fluorescent material in finely divided powder form in a liquid carrier.

The luminescent porous layer can be prepared by using non-luminescent cloth, mesh or porous layer material, dyed or coated with fluorescent dye or pigment or by binding together fluorescent material in granular form, using resin or adhesive agent, to form a porous structure. The electrophoretic material need not be luminescent when the suspension medium or the porous layer is luminescent; non-luminescent electrophoretic material which can be used includes, for example, carbon black, graphite or titanium dioxide. Black pigment may be opaque due to absorption of visible light and white pigment may be opaque due to reflection of visible light.

An electrophoretic material suspended in a suspension medium usually has a charge which is positive or negative depending upon the properties of the electrophoretic material and the suspension medium.

The electrophoretic suspension layer 27 or 37 of Figures 1*a* or 2*a* can consist of a single electrophoretic material of either positive or negative polarity, suspended in a suspension medium. The electrophoretic suspension layer 42 or 44 of Figures 3*a* or 4*a* must include at least two kinds of electrophoretic materials suspended in the medium. These two kinds of electrophoretic materials must have different luminescent properties, and different charge polarities or electrophoretic mobilities. Accordingly, in preparing an electrophoretic suspension layer such as 42 or 44, at least two electrophoretic materials having suitable luminescent properties and electrophoretic properties must be selectively suspended in the suspension medium.

The suitable average particle sizes of the finely divided particles depend upon the stability of the resultant electrophoretic suspension, and lie usually in the range from 0.1μ to 50μ.

It is advantageous to add a suitable charge control agent, dispersion agent or stabilizing agent to the electrophoretic suspension layer in order to provide a stable suspension layer. To control the charge property of the suspended particles, it is preferred to use particles coated with a resin which is not soluble in, or only partially soluble in, the suspension medium. If the coating resin is partially soluble in the suspension medium, it can also act as a fixing agent for a displayed image.

There can be used, as a suspension medium any suitable liquid which is inert to the electrophoretic material, the porous layer, the housing and the electrode. For producing a temporary display there can be used as a suspension medium in a liquid state at room temperatures, that is from 0°C to 35°C. Suitable suspension media include, for example, kerosene, trichlorotrifluoroethane, isopropyl alcohol, mineral oil, liquid paraffin or olive oil. For producing a permanent display, that is, a permanent or semi-permanent copy, the suspension medium may be one which is in a solid state at room temperature but can be rendered fluid or liquid above room temperatures, that is, above 35°C. Such media

include, for example, waxes such as beeswax vegetable wax, paraffin or synthetic wax.

When using these waxes and similar materials, the device, or at least the suspension layer, must be kept at a suitable temperature above room temperature, for recording the display. After the device has been subjected to the direct electric field at the higher temperature and the spatial distribution of the electrophoretic material, varied electrophoretically, the device is cooled to room temperature to produce a permanent display. If it is desired to erase such a display, the device is subjected to an alternating or direct electric field at the higher temperature. Once the material of the suspension layer has hardened, an electric field applied to the electroluminescent suspension layer to render it visible does not change the distribution of the electrophoretic material and the permanent image is retained.

The suspension medium may consist of a thermosettable material which is in a liquid state at room temperature; a completely permanent display is then obtained by producing the desired distribution of the electrophoretic material and then setting the medium by the application of heat.

Thermosetting materials which can be used as suspension media in this way include, for example, drying oil such as linseed oil, soya oil or tung oil. The liquid suspension medium may include a binder such as polystyrol, vinyl acetate resin or linseed oil which fixes the electrophoretic material in a finely divided powder form, and a hard copy having a permanently visible image reproduced thereon can be obtained by evaporating or extracting the residual medium. The evaporation or extraction of the medium can be effected by reduced pressure applied to the medium, for example, by evacuating the housing including electrophoretic material in the suspension medium through an outlet formed in a wall of the housing.

Suitable housings can be made of any available material which is inert to the suspension medium and the electrophoretic material. For example, the frame 23 can be formed from a plastic sheet having a central opening. One of the two walls can be provided with a metal plate secured by adhesive to the frame; such a plate may serve as one electrode as described. The other wall can be provided by a transparent glass plate secured to the frame by adhesive, the plate having on it a transparent conductive thin film such as a film of tin oxide, cuprous iodide or metal. The transparent conductive thin film is in contact with the electrophoretic suspension layer. To provide a device with a radiation source located behind the panel the metal plate can be replaced by a second transparent glass plate with a conductive film on it. These methods of construction are given by way of example only, and any of a variety of methods can be adopted.

In assembling the device the electrophoretic suspension can be introduced by providing a housing with only one major wall attached, pouring in the suspension and then attaching the closing wall, or the housing can be completed but for an inlet in one wall through which the suspension is poured, and the inlet closed when the housing has been filled.

Improved operating life can be obtained by coating at least one of the electrodes with an insulating layer in contact with the suspension layer. This insulating layer improves the resistance of the suspension layer to electrical breakdown and permits the use of higher electric voltage. The layer also makes it easier to remove the electrophoretic material from the electrode surface when forming a new image by subjecting the device to the appropriate electric field.

Figure 11 shows an example of a construction using an insulating layer; a first electrode 28 is coated with an insulating layer 70 which is insoluble in the suspension medium. The other electrode 29 or both electrodes can be so coated with insulating material. The insulating layer can be provided by coating the electrode with, for example, vinyl acetate resin, polystyrol or gelatin, which forms a transparent insulating layer suitable for a transparent wall of the housing. The thickness of the layer 70 depends on the electrical resistance which it is desired that the layer and the electrophoretic suspension layer 22 should have. For operation at a low voltage it is desirable that the insulating layer 70 should have an electrical resistance no greater than that of the suspension layer 22.

The suspension layer can be divided to present a series of individual cells or chambers, nested to form a composite layer. For example, as shown in Figure 12a the suspension layer 50 is split up by a plurality of spacers 71 extending traversely of the layer so as to present a number of cells 72 each containing the suspension. The spacers can be provided by a sheet of material 73 having holes therein, as shown in Figure 13, used so as to divide the suspension layer into separate chambers or cells.

The cells, formed by holes 74 or otherwise, can have any suitable shape, such as square, as shown in Figure 13, circular, rectangular, hexagonal, and so on. The cells can be regular or irregular in shape and may vary widely in dimension and disposition or order. The dimensions of the cells are selected in accordance with the desired